DEVELOPMENT AND CHARACTERISATION OF TREATED KAOLIN FILLED POLYPROPYLENE/KAOLIN NANOCOMPOSITES

SHEHU YAHAYA

A thesis submitted in
fulfilment of the requirement for the award of the
Doctor of Philosophy in Science

Faculty of Applied Sciences and Technology
Universiti Tun Hussein Onn Malaysia

MAY 2018

DEDICATION

Specially dedicated to Allah Subhaana Wa Ta'ala (SWT) that gave me the strength to undertake this research work and my late parents (mother and father; Malama Salimatu and Mallam Yahaya); May Allah (SWT) rest their souls in perfect peace. Ameen.

ACKNOWLEDGEMENTS

In the name of the Almighty ALLAH, the most Beneficent and Merciful, with His grace and blessing has directed me to the success completion of this work. My utmost gratitude is to Allah SWT. May the Peace and Blessings of Allah SWT continue to be upon the Prophet Muhammad (SAW) and his companions. First and foremost, I would like to express my profound gratitude to my supervisor Dr. Suzi Salwah Bint. Jikan. May Allah SWT reward you abundantly for your patience, encouragement, excellent spiritual and academic advices, perpetual listening ear, marvellous delivery and countless apprehension and readiness to provide assistance to me during this study. My co-supervisor, Dr. Nur Azam Bin Badarulzaman deserves sincere appreciations. Thank you very much for your caring observations, opinions and advices. Honestly, the merits is to my supervisors for their inspiration in the research processes, thank you so much for propagating such a treasure of wisdom.

I also wish to express my appreciation to entire FAST and FKMP, all lab technicians who assisted me in the research experiments and UTHM community. May Allah SWT bless you all. My profound gratitude goes to my parents Mal. Salimatu Muhammad and Mall. Yahaya Muazu. May Allah SWT rest their souls in perfect peace and make Aljanatul Firdaus their eternal abode.

I sincerely thank my entire family who are very understanding, especially my beloved wife, Ameenah Mahmud and children (Habiba, Umar, Muhammad, Salimatu, Mahmud, Yahaya and Abdullah). I say a most heartfelt love and thank you for proving understanding atmosphere and support during my absence at home for this struggle. A big thanks my research group members including Shehu I. D, Dahiru A. A,Muhammad Z, Awwal N, Rozainita R, and Nazia. I also wish to specially thank my colleagues especially; Muhammad U. Bello, Muhammad I.K, Jibrin Y.B, Muhammad N, Muhammad M.N, Aliyu I, Musa M; to mention but few.

ABSTRACT

This research work focused on producing modified kaolin filler in polypropylene/kaolin (PP/K) nanocomposite by melt compounding process in order to improve its mechanical and thermal properties for industrial applications. The surface treatments of micron sized Malaysian kaolin were conducted to produce nano sized kaolin by acidification of kaolin fillers with sulphuric acid and planetary milling using urea (mechanochemical milling). Testing on both surface treated kaolin were carried out with the aid of Field Scanning Electron Microscopy (FESEM), Fourier Transform Infrared (FTIR), Brunauer–Emmett–Teller (BET), X-ray Diffraction (XRD) and Particle Size Analyser and results of both treated kaolin were compared. However, the surface treated kaolin using acidification was unsuccessful as shown by XRD, FTIR and BET results. A successful delamination of micron sized into nano sized kaolin was achieved by mechanochemical milling. The additional bands at 3624, 3445 and 3388 cm^{-1} and illite phase at lower 2θ by FTIR and XRD studies respectively, indicated delamination of kaolin. Surface area increased by 400% from BET results. The PP/K nanocomposite was produced by incorporating low weight (1-7%) percentages of organically modified nanokaolin into PP by melt compounding with polypropylene grafted maleic anhydride (PP-g-MA) as coupling agent. The FTIR and XRD analyses on chemical structure showed successful synthesis of PP/K nanocomposites by the vanishing of characteristic of OH bands and peaks of kaolin respectively. The tensile and impact strength, tan δ, loss modulus and melt flow index of PP/K nanocomposite decreases by 17, 27, 36, 32 and 78% respectively. Conversely, the results show that incorporation of nanokaolin clay into PP causes increase in thermal degradation (200%), crystalinity (17%), nucleation effect (17%), storage modulus (10%), surface roughness (87%), and optical (262%). Whereas, TEM of PP/K nanocomposite exhibit nanokaolin dispersion with nanoscale sizes. Therefore, the PP/K nanocomposites formulated shall be a potential candidate for manufacturing novel new materials of attraction in many sectors.

TABLE OF CONTENTS

TITTLE **i**
DECLARATION **ii**
DEDICATION **iii**
ACKNOWLEDGEMENTS **iv**
ABSTRACT **v**
ABSTRAK **xi**
TABLE OF CONTENTS **vi**
LIST OF FIGURES **xi**
LIST OF TABLES **xv**
LIST OF APPENDICES **xvi**
LIST OF SYMBOLS AND ABBREVIATIONS **xvii**

CHAPTER 1 INTRODUCTION **1**
1.1 Research background 1
1.2 Problem statement 6
1.3 Research objectives 8
1.4 Research scope 9
1.5 Significance of the study 10

CHAPTER 2 LITERATURE REVIEW **11**
2.1 Introduction 11
2.2 Clay mineral fillers for polymer nanocomposites 13
2.2.1 Kaolin clay 14
2.2.2 Elemental analysis of Malaysian kaolin 17
2.3 Surface treatments of kaolin 18
2.3.1 Kaolin surface treatments with acids 22
2.3.2 Kaolin surface treatments using urea 23
2.4 Polymer matrix nanocomposites (PMCs) 25

2.4.1 Polymeric matrices 31
2.4.2 Reinforcements 33
2.4.3 Additives 34
2.5 Polypropylene (PP) and its nanocomposites 36
2.6 Polypropylene/kaolin (PP/K) nanocomposites 39
2.7 Properties and characterizations of PP/K nanocomposite 42
2.8 Mechanical properties of PP/K nanocomposites 44
2.8.1 Tensile strength 45
2.8.2 Charpy impact strength 47
2.8.3 Dynamic mechanical analysis (DMA) in nanocomposites 49
2.9 Melt flow properties of PP/K nanocomposite 50
2.10 Optical properties of PP/K nanocomposite 52
2.11 Thermal properties of PP/K nanocomposite 54
2.11.1 Differential scanning calorimetry (DSC) in PP nanocomposites 55
2.11.2 Thermal gravimetric analysis 57
2.12 Morphological properties of PP/K nanocomposite 58
2.12.1 Scanning electron microscopy 58
2.12.2 Atomic force microscopy 60
2.12.3 Transmission electron microscopy 62
2.13 Chemical structure analyses of PP/K nanocomposite 63
2.13.1 Fourier transform infrared spectroscopy 63
2.13.2 X-ray powder diffraction 64
2.14 Applications of PP/K nanocomposites 66

CHAPTER 3 METHODOLOGY 69

3.1 Introduction 69
3.2 Materials 70
3.3 Kaolin surface treatment with sulphuric acid 71
3.4 Kaolin surface treatment with urea using mechanochemical milling 72
3.5 Sample preparation of Polypropylene/kaolin (PP/K) nanocomposites 73

3.6 Samples characterisations 76
3.6.1 Elemental analysis 76
3.6.2 Particle size analysis 76
3.6.3 Surface area analysis 77
3.6.4 Mechanical properties of PP/K nanocomposites 77
3.6.4.1 Tensile strength (MS ISO 527) 77
3.6.4.2 Impact test (MS ISO 179) 78
3.6.5 Melt flow properties of PP/K nanocomposite 79
3.6.6 Optical properties PP/K nanocomposite 80
3.6.7 Thermal properties of PP/K nanocomposite 80
3.6.7.1 Differential scanning calorimetry 81
3.6.7.2 Thermogravimetry analysis 82
3.6.8 Morphological analyses 83
3.6.8.1 Field scanning electron microscopy (FESEM) 83
3.6.8.2 Atomic force microscopy (AFM) 85
3.6.8.3 Transmission electron microscopy (TEM) 85
3.6.9 Chemical structure analyses 86
3.6.9.1 Fourier transform infrared (FTIR) 86
3.6.9.2 X-ray powder diffraction (XRD) 87
3.6.10 Dynamic mechanical analysis (DMA) 89

CHAPTER 4 RESULTS AND DISCUSSION 91
4.1 Introduction 91
4.2 Kaolin surface treatment with sulphuric acid 91
4.2.1 Particle size analysis 92
4.2.2 Chemical structure analyses 98
4.2.2.1 Fourier transform infrared spectroscopy 98
4.2.2.2 X-ray diffraction (XRD) 99
4.3 Kaolin surface treatment with urea using the mechano-chemical method 101
4.3.1 Particle size analysis 101
4.3.2 Surface area analysis 104
4.3.3 Morphological analysis 107

4.3.4 Chemical structure analyses 110
4.3.4.1 Fourier transform infrared spectroscopy 110
4.3.4.2 X-ray diffraction 112
4.4 Elemental analyses of kaolin before and after treatment with H_2SO_4 acid and urea 114
4.5 Polypropylene/kaolin (PP/K) nanocomposites 118
4.6 Mechanical properties of PP/K nanocomposites 119
4.6.1 Tensile strength of PP/K nanocomposites 119
4.6.2 Charpy impact strength 122
4.6.3 Dynamic mechanical analysis (DMA) 124
4.7 Flow properties of PP/K nanocomposites 128
4.7.1 Effect of kaolin loading 128
4.7.2 Effect of temperature 129
4.7.3 Effect of pressure 131
4.8 Optical properties of PP/K nanocomposite 131
4.9 Thermal properties of PP/K nanocomposites 134
4.9.1 Crystallization behaviour 134
4.9.2 Nucleation activity 139
4.9.3 Crystallization activation energy 140
4.10 Thermal degradation of PP/K nanocomposites 142
4.10.1 Effect of kaolin loading 142
4.10.2 Effect of temperature 144
4.10.3 Effect of pressure 145
4.11 Morphological properties of PP/K nanocomposites 146
4.11.1 Field scanning electron microscopy (FESEM) 146
4.11.2 Atomic force microscopy (AFM) 149
4.11.3 Transmission electron microscopy (TEM) 151
4.12 Chemical structure analyses of PP/K nanocomposite 154
4.12.1 Fourier transform infrared spectroscopy (FTIR) 155
4.12.2 X-ray powder diffraction 156

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS 159
5.1 Conclusion 159
5.2 Recommendations 161

REFERENCES **162**

APPENDICES **192**

VITA

ABSTRAK

Penyelidikan ini tertumpu kepada penghasilan pengisi kaolin yang diubahsuai dalam nanokomposit polipropilena/kaolin (PP/K) secara penyebatian leburan untuk meningkatkan sifat mekanikal dan termanya bagi aplikasi perindustrian. Rawatan permukaan telah dilakukan pada kaolin bersaiz mikron bagi menghasilkan kaolin bersaiz nano menerusi pengasidan pengisi kaolin dengan asid sulfurik, dan pengisaran planet dengan urea (pengisaran mekanokimia). Kedua-dua kaolin terawat permukaan telah diuji dengan Mikroskop Elektron Pengimbasan Medan (FESEM), Infra Merah Penjelmaan Fourier (FTIR), Brunauer-Emmett-Teller (BET) serta Pembelauan Sinar-X (XRD), dan keputusan ujian kedua-dua kaolin tersebut telah dibandingkan. Kaolin terawat secara pengasidan adalah tidak berhasil seperti yang ditunjukkan oleh ujian XRD, FTIR dan BET. Pelekangan mikron bersaiz besar ke dalam kaolin bersaiz nano telah dicapai dengan pengisaran mekanokimia. Jalur tambahan pada 3624, 3445 dan 3388 cm^{-1} dan fasa illit pada sudut 2θ yang kecil menerusi FTIR dan XRD masing-masing, menunjukkan pelekangan kaolin. Kawasan permukaan meningkat 400% menerusi ujian BET. Nanokomposit PP/K dihasilkan dengan menggabungkan peratusan nanokaolin organik yang rendah secara organik (1-7%) dan polipropilena terubahsuai maliek anhidrida (PP-g-MA) sebagai agen pengganding dengan meleburkan penyebatian. Analisis kimia menerusi FTIR dan XRD menunjukkan kejayaan sintesis nanokomposit PP/K apabila ciri-ciri jalur OH dan puncak kaolin masing-masing tidak dapat dikesan. Kekuatan tegangan dan hentaman, tan δ, modulus kehilangan dan indeks aliran leburan nanokomposit PP/K masing-masing berkurang 17, 27, 36, 32 dan 78%. Penambahan tanah liat nanokaolin ke dalam PP telah meningkatkan degradasi haba (200%), kehabluran (17%), kesan penukleusan (17%), modulus penyimpanan (10%), kekasaran permukaan (87%), dan optik (262%). Ujian TEM terhadap nanokomposit PP/K mempamerkan serakan kaolin bersaiz nano. Oleh itu, nanokomposit PP/K ini berpotensi dalam penghasilan bahan novel menarik di pelbagai sektor.

LIST OF FIGURES

1.1	Map of Malaysia showing the location industrial mineral reserves of peninsular Malaysia	8
2.1	Structure of kaolin	15
2.2	Structure of layered silicate of type 2:1	15
2.3	Schematic illustration of a representative XRF system	17
2.4	Benzamide	21
2.5	Ethyl pyridinium chloride	21
2.6	Mechanism of intercalation of urea and kaolin	25
2.7	Monomer of polypropylene	37
2.8	Molecules of PP polymer in isotactic, syntactic and atactic forms	38
2.9	Structure of three major types of layered silicates in polymer matrix	39
2.10	Tensile test machine (Maiti and Lopez, 2005)	46
2.11	Impact test machine (Hussain *et al.*, 2006)	48
2.12	General Schematic of DMA instrument	50
2.13	Outline of the dimension of melt flow index	51
2.14	Schematic diagram of UV-Spectrometer	54
2.15	Schematic diagram of a differential scanning calorimeter	56
2.16	The schematic diagram of the thermogravimetric analyzer configuration	57
2.17	Scanning Electron Microscopy	59
2.18	Schematic illustration of AFM	61
2.19	Schematic illustration of the TEM	62
2.20	Schematic illustration of classic FTIR spectrometer	64
2.21	Schematic illustration of 2D-XRD	65
3.1	Research framework	70
3.2	Fritch Pulverisette 6 planetary milling machine	72
3.3	Elmasonic E30H ultrasonic bath	73
3.4	PW 3000 two-roll mill	74

3.5	NP7- 1F injection moulding machine	74
3.6	Images representing samples for (a) Tensile test and (b) Impact test	75
3.7	Lloyd instrument tensile strength machine	78
3.8	Zwick/ Roell 4106 instrument melt flow index machine	80
3.9	Universal V4.5A TA DSC instrument	82
3.10	Result data of thermogravimetry analysis	83
3.11	JEOL JSM-7600F FESEM machine	84
3.12	JEOL-H-800 TEM machine	86
3.13	Perkin Elmer Spectrum 100	87
3.14	XRD Model Bruker D8 Advance	89
4.1	Particle size distribution of untreated and treated kaolin at different H_2SO_4 of concentrations	93
4.2	FESEM micrographs observed at magnification of 5,000× for untreated and treated kaolin at different H_2SO_4 concentrations	95
4.3	FESEM micrographs observed at magnification of 500× and EDX analyses of before and after kaolin treatment with different H_2SO_4 concentrations	97
4.4	FTIR of untreated and treated kaolin at different H_2SO_4 concentrations	99
4.5	XRD of untreated and treated kaolin at different H_2SO_4 concentrations	101
4.6	Particle size distribution of (a) untreated kaolin, and (b) treated kaolin using urea	102
4.7	N_2 adsorption/desorption isotherms of (a) untreated and (b) treated kaolin	105
4.8	Pore size distribution of untreated kaolin (UK)	107
4.9	Pore size distribution of treated kaolin (TK)	107
4.10	FESEM micrographs displaying the morphological alterations of the kaolin crystals as a result of mechano-chemical milling	108
4.11	SEM-EDX analyses of (a) untreated and (b) treated kaolin with urea	110
4.12	FTIR of urea, untreated and treated kaolin samples	111
4.13	XRD patterns of untreated and delaminated kaolin	114
4.14	Tensile strength of PP/K nanocomposites at different kaolin loadings	120
4.15	Impact strength of PP/K nanocomposites at different kaolin loading	122
4.16	FESEM micrographs displaying the fracture part of impact test	124
4.17	DMA spectra of PP and PP/K nanocomposites	127

4.18	The MFI values of PP/K nanocomposites obtained at different kaolin loadings	129
4.19	The MFI curves of PP/K nanocomposites obtained at different processing temperature	130
4.20	The MFI values of PP/K nanocomposites at different pressure	131
4.21	Reflectance spectra of pure PP and various PP/K nanocomposites	133
4.22	DSC crystallisation curves of PP and PP/K nanocomposites with different nanokaolin loadings	135
4.23	DSC melting curves of PP and PP/K nanocomposites with different nanokaolin loadings	136
4.24	Non-isothermal crystallisation curves of PP and PP/K nanocomposites	137
4.25	Effective activation energy of PP and PP/K nanocomposites	141
4.26	Kissinger plot for determining non-isothermal crystallization activation energy of PP with variation of nanokaolin content	141
4.27	TGA curves of netPP and PP/K nanocomposites	144
4.28	FESEM micrographs of (a) Pure PP, (b) PPNK5, (c) PPK5 and (d) PPK7 (magnification of 5,000×)	147
4.29	FESEM fractographs for samples of (a) pure PP, (b) PPK1, (c) PPK3, (d) PPK5 and (e) PPNK5 (magnification of 1,000×)	148
4.30	AFM 2D and 3D topographic images of (a) PP (b) PPK1 and (c) PPK3 (d) PPK5 and (e) PPK7	150
4.31	TEM micrograph for PPK5 nanocomposites with 5 wt% of nanokaolin	152
4.32	TEM micrograph for PPK3 nanocomposite with 3 wt% of nanokaolin	153
4.33	TEM micrograph for PPK1 nanocomposite with 1 wt% of nanokaolin	154
4.34	FT-IR spectra of pure PP, PPK1, PPK3 and PPK7	156
4.35	XRD spectra of PP and PP/K nanocomposites	158

LIST OF TABLES

2.1	Surface reformations of kaolin	19
2.2	Commonly used operational additives for PP matrix.	36
2.3	Commonly used characterisation techniques and their properties (Zeng *et al.,* 2005).	44
2.4	Types of thermal analysis	55
3.1	Formulation of blends of the PP/K nanocomposites samples	75
4.1	Particle size and surface area analyses (SSA) of kaolin samples	93
4.2	The corresponding wavenuber of silica	98
4.3	Particle size analyses of untreated and treated kaolin with urea	103
4.4	Surface properties of untreated and treated kaolin samples	106
4.5	EDX of kaolin samples before and after urea treatment	109
4.6	Mineralogical compositions of kaolin samples treated with H_2SO_4 acid	114
4.7	Mineralogical composition of kaolin samples treated with urea	117
4.8	Comparison between surface treated kaolin particles using H_2SO_4 acid and urea	118
4.9	The DSC results of PP and PP/K nanocomposites	140
4.10	Crystallization activation energy change ΔE and crystallization half-time ($t_{0.5}$) of the samples	142
4.11	Thermal stability of pure PP and PP/K nanocomposites	143
4.12	TGA data of PP and PPK5 attained in atmosphere (oxidative)	145
4.13	Surface roughness of PP and PP/K nanocomosites	151
4.14	Assignment of principle bands of kaolin and PP	155

LIST OF APPENDICES

A	List of publications	192
B	Data sheet polypropylene	200
C	Data sheet kaolin	202
D	Data sheet polypropylene grafted malaiec anhydride	204
E	Data sheet sulphuric acid	206
F	Data sheet urea	217

LIST OF SYMBOLS AND ABBREVIATIONS

AFM	Atomic force microscopy
ASTM	American Standards Test Method
BET	Brunauer-Emmet-Teller
cm^2	Square centimeter
cm^3	Centimeter cubic
$^oC/min$	Degree celsius per minute
d	Interspacing between diffraction lattice plane
DMA	Dynamic mechanical analysis
DSC	Differential scanning calorimetry
EDX	Energy dispersive X-ray
FESEM	Field emission scanning electron microscopy
FTIR	Fourier transform infra-red
g	Gram
GPa	Giga pascal
H_f	Heat of Fusion
HRTEM	High resolution transmision electron microscopy
K	Kaolin
MFI	Melt flow index
mg	Milligram
PP	Polypropylene
PP-g-MA	Polypropylene grafted malaeic anhydride
PP/K	Polypropylene/kaolin
PMCS	Polymer matrix composites
PNC	Polymer nanocomposites
SAXS	Small-angle X-ray scattering
SSA	Specific surface area
T_c	Crystallization temperature

TEM	Transmission electron microscopy
T_g	Glass transition temperature
TGA	Thermogravimetric analysis
WAXRD	Wide angle X-ray diffraction
wt%	Weight percent
X_c	Crystallinity content
XRD	X-ray diffraction
α	Alpha
θ	Diffraction angle
λ	Wavelength
μm	Micron
ΔH_{100}	Theoretically heat of fusion of 100% crystalline polymer

CHAPTER 1

INTRODUCTION

1.1 Research background

Demands for high performance materials have been increasing day-in, day-out, hence the focus of current research has been manufacturing products with superior properties at slight deviations in the tools, procedures and cost of operations (Krishnan *et al.*, 2013). Surface treatments are more precisely on surface engineering or alteration of surfaces in engineering to the definite anticipated properties. It leads to enhancement in surface area, regulation of friction and wear, advance corrosion opposition, alterations in physical properties (for example reflection, resistivity and conductivity), modification of the material dimension, adaptability of appearance (such as roughness and color) and reduce cost (Lee, 2000). These could be achieved through acidification (refluxing), ion-exchange method (Shah *et al.*, 2016), mechanical comminution (Wang *et al.*, 2012) and grafting-intercalation using dry-grinding method (Makó *et al.*, 2009).

Nanocomposites have an annual growth rate of approximately 25% and they are the largest group to be in engineering plastics and elastomers (Henrique *et al.*, 2009). Once, the levels of technology turn out to be more sophisticated, the materials used are expected to be satisfyingly more efficient. Several performance features are expected from these materials. For instance, the materials for high-end applications, such as aerospace engineering should have higher performance efficiency and reliability if compared to that of other engineering applications. The materials have to be light weight for many applications including thermoplastic storage compartments used in airplanes. The resulting products have to be energy efficient

and cost effective (Sinha and Okamoto, 2003). In the automotive industries, constituents for the under hood, exterior and interior, are progressively substituting metal components by reinforced composites owing to decrease in their weights, better-quality functioning, additional beautiful look and consistency. In the present development polypropylene (PP) is the greatest extensively consumed polyolefin which more than half of the entire plastic materials are accountably are used in automobiles (Hasegawa *et al.*, 1998). In addition, the materials used must have good blend of properties, such as enhanced tensile and flexural strength. To sum up, these products of modern technological source may also need to function in environments that are extreme, such as, very high temperature (the order of 2500K), cryogenic conditions, highly corrosive, vacuum (as in space), high hydrostatic pressure (as in deep sea), high electric, and magnetic or irradiation fields (Mittal, 2009).

The conventional materials may not always be capable of meeting the demands of such above-mentioned extreme environments. New materials are being created for meeting these performance requirements. Thus, polymer composite materials had been developed as one class of such material system. As a challenge to accomplish these objectives, researchers are exploring several polymer nanocomposites with diverse fillers and additives (Hegde, 2009); including evolution from microfiller to nanofiller particles which produces dramatic changes in physical and chemical properties of such materials. The materials that are in nanoscale have larger surface area for a given volume (Luo and Daniel, 2003) than conventional ones (micron sized materials). A nanostructured material can have substantially different properties from larger-dimensional material of the same composition.

Polymer nanocomposites are polymers (thermoplastics, thermosets or elastomers) which have been reinforced with small amount (< 5% by weight) of fillers of very high aspect ratio (AR > 300). The aspect ratio of a geometric shape is the ratio of its sizes in different dimensions. (Throne, 2005). High aspect ratio nanoparticles (HARN) are nanoparticles with a length many times that of their width. In previous decades, polymer nanocomposites have risen as a novel class of materials and fascinated substantial interest in research and development activities universally (Zeng *et al.*, 2005). Polymer nanocomposites are still one of the dynamically development materials and has a long history. The production and characterisation of new and novel materials are part of the leading objectives of advanced material research. The task to yield stronger, tougher, light-weight

materials continues rapidly, being determined by demands for property enhancements, economy and material obtainability (Browska, 2013). In order to improve polymer properties, the introduction of small amount (up to 5% wt.) of inorganic nanofillers in polymer matrices is a motivating technique. Among the roles played by low amount of fillers is that density of final product are reduced; leading to advanced fuel efficiency and reduced pollution. It is obvious that nanocomposites offer similar or improved properties at considerable lower filler loading levels than materials with conventional fillers.

Addition of nanofillers to polymers allows us possibly to produce composite materials with upgraded mechanical and barrier properties, flame retardancy, electrical conductivity. This is mainly due to their new and frequently much enhanced mechanical, thermal, electrical and optical properties as compared to their macro- and micro-counterparts. The aim of the fabrication of thermoplastic composites is mostly directed by price performance relationship. Mineral fillers have made a significant input to the remarkable growth of thermoplastic polymers composites (Meziane *et al.,* 2016). This emphasis on filled polymer composites is due to a combination of factors. In addition to reduction of price of the final material, mineral fillers can equally help to increase shrinkage on moulding, stiffness and flammability, which are the major limitations of the bulk thermo-plastics. The mechanical and other properties of composites were affected by fillers depending on their shape, particle and aggregate sizes, surface characteristics, and degree of dispersion (Guessoum *et al*., 2012).

Precisely, polymer nanocomposites prepared by using layered inorganic substrates display high heat distortion temperatures, improved flame resistance, better modulus values, enhanced barrier properties and reduced thermal expansion coefficient at low cost (Gilman *et al.,* 2000). The synergistic effects of the nano scale structure and particle–particle interactions are likely responsible for these improved properties protracted to the polymer surfaces. The profound understanding of polymer nanocomposites was achieved by developments in microscopy: scanning tunnelling microscopy, scanning electron microscopy and transmission electron microscopy. By means of these authoritative characterisation tools, scientists can understand better and account for surface topology, structure and morphology up to atomic scale (Hegde, 2009). Consequently, the nanocomposite technology has

initiated novel engineering materials with an efficient and countless strategy in upgrading the new structural and functional properties of synthetic polymers.

The types of polymers used in preparation of polymer nanocomposites include:

i. Vinyl polymers which consist of the vinyl addition polymers derivative of conventional monomers such as acrylic acid (Sinha and Okamoto, 2003), acrylonitrile, methyl methacrylate (Blumstein and Malhotra, 1970), methyl methacrylate copolymers, other acrylates and styrene.

ii. Condensation (step) polymers; numerous mechanically significant polycondensates have been utilised in nanocomposites formulation through layered silicate. These comprise of poly(1-caprolactone) (PCL), N6 (Parfitt and Greenland, 1970; Lindström *et al.*, 2016), several other polyamides and polybutadiene.

iii. Polyolefins for instance polypropylene (PP) (Kaempfer *et al.*, 2002), polyethylene oligomers, poly(ethylene-covinyl acetate) (EVA) polyethylene (PE) (Rong *et al.*, 2001) have been used.

iv. Specialty polymers adding to the above stated common involving polymeric materials that would not include the use of poisonous or harmful constituents in their production, and might permit degradation through an environmental composting course. Consequently, polylactide (PLA) is of growing marketable attention since it is prepared from renewable sources and voluntarily biodegradable (Henrique *et al.*, 2009). Other biodegradable polymers for preparation of nanocomposites are unsaturated polyester, poly(butylene succinate) (PBS), aliphatic polyester (Maiti *et al.*, 2007) and polyhydroxy butyrate.

Polypropylene (PP) compatibility with fillers has been improved by matrix modification by grafting it with reactive moieties, such as acrylic acid, acrylic esters, and maleic anhydride (Lee *et al.*, 2008). Obviously, there is a countless incentive to use completely the commercially and low-cost essential thermoplastic polymers, however, in several terms, the major markets are in PVC and polyolefin for as many applications as possible (Meziane *et al.*, 2016). PP is one of the most adaptable product thermoplastics with heat resistance, unlimited crystalinity, special moisture barrier, routine optical properties, low cost, high thermal stability and low density with high processability and recyclability. Conventional fillers include silicates, talc,

calcium carbonate and fibers. Out of the inorganic fillers that can be in cooperated into PP to improve its properties; clays are recognised to acquire several advantageous differences on stiffness, hardness, toughness and heat resistance (Lee *et al*., 2005).

Kaolin is very much in abundance in Malaysia clayey soil, which can be made to reinforce PP to improve its properties at low cost of manufacture. The name kaolin perhaps originated from the Chinese term kauling, denotation for high ridge, the title of a hill near Jauchau Fu, China, somewhere the material was excavated centuries ago (Kotal and Bhowmick, 2015). It has fascinated additional and extra attention for its plentiful, low cost, and shielding effect in polymer. Kaolin are used in making tires, solid rubber tires, splash guards/wheel covers, seals/gaskets/o-rings, insulators, hose/belts, white roofing membranes, wire/cable, flooring, medical rubber goods, footwear and printing. Even though the chemical composition of kaolin is alike to halloysites, it differs by having a predominantly plate-like structure (Tang *et al*., 2017).

Kaolin ($Al_2Si_2O_5(OH)_4$) represents a 1:1 phyllosilicate with a gibbsite octahedral layer and a silicon oxide tetrahedral sheet. It is an asymmetric structure which allows the creation of hydrogen bonds among consecutive layers, developing a great cohesive energy. As the inorganic surface of the particles is tremendously polar while the PP is nonpolar, the interface interaction can be produce only by molecular modification of one or both components (Teng *et al.*, 2015). Therefore, to cultivate a good dispersion, the surface reformation of kaolin can be achieved either by the means of coupling agents, or through the intercalation of chemical species in the interlayer gallery, hence increase the basal spacing of the clay which may affluence the intercalation of polymer chains between its plate-likes (Guessoum *et al.*, 2012).

Since the inorganic surface of the clay flakes is extremely polar whereas the PP is apolar, the boundary interface can be offered only by molecular reformation of one or both constituents (Guessoum *et al.*, 2012). Therefore, for a good dispersion., the surface treatment of kaolin can be accomplished either by the employment of coupling agents, otherwise by the intercalation of chemical groups in the interlayer passageway, to enlarge the basal spacing of the clay that will ease the intercalation of polymer chains among its clay particles (Frost *et al.*, 2002). Similarly, some of the chemical groups which can be directly inserted in the interlayer of the kaolinite are limited as a result of great cohesive energy between the clay layers. Horváth *et al*.,

(2005) stated that urea is one of the highly recognised compounds that can absolutely intercalate into kaolinite layers. Additional compounds that can also easily integrate into the kaolin flakes are dimethylsulphoxide (DMSO), potassium acetate, formamide and hydrazine (Valášková *et al*., 2011).

In addition, the incompatibility held between the hydrophilic clays and non-polar hydrophobic PP inhibits suitable clay dispersal (Lertwimolnun and Vergnes, 2005). Accordingly, excessive attempts have been formulated to utilise the operational polyolefin oligomers as compatibilisers, adapted by any hydroxyl groups (OH) or maleic anhydride (MA) in form of polypropylene-grafted-maleic anhydride (PP-g-MA). These modifiers contain a definite amount of polar groups (i.e. –COOH, –OH) to incorporate between silicate sheets via hydrogen or additional chemical bond involved negative charges or in the oxygen group of the silicate plates (Dong and Bhattacharyya, 2008). Obviously, clay agglomerates are simply fragmented up and even dispersal of clay flakes can be prominently accomplished in the existence of PP-g-MA (Zdiri *et al.*, 2017).

The goal of this study is to synthetize PP nanocomposite by melt compounding; to improve its thermal and mechanical properties using organoclay (urea–kaolin intercalates) and PP as matrix with polypropylene maleic anhydride (PP-g-MA) as compatibilliser; then characterise their dispersion and morphology. The result is expected to make a great impact in the Malaysia economy and business and world at large.

1.2 Problem statement

The processing of polymer silicates nanocomposites to meet up with increasing mandate for high performance materials has been challenging. Kaolin is hydrophobic and polymers are hydrophilic (e.g. PP); obtaining uniform dispersion of fillers into the matrix through intercalation, porous assembly and surface loading tends to be difficult. Thus challenges in technological development of transition from micro to nanoparticles arises in today's research (Lv *et al.*, 2008). Modification of kaolin surface is therefore necessary. As a results, splitting along the (d_{001}) planes, cracking in platelets and rise in surface area occurs When fillers are added to a polymer matrix, will develop several properties of the composite material though it could have

a negative effect on a few other properties such as optical properties. Hence, it is of an excessive significance to have a balance among different properties; such as upgrading the properties of polymers; thermally and mechanically with increase barrier of PP.

Recently, mineral based functional composites has been successfully technologically advanced through compounding of a functional matrix (such as polypropylene, polyaniline and polyvinylchloride) and silicate materials (such as kaolin, bentonite and montmorillonite) at micro-nano level, by use of techniques such as intercalation, porous assembly and surface loading. These has been challenging in today's research. Classically, nanomaterials currently under investigation include nanoparticles, nanofibers, nanotubes, fullerenes, and nanowires. However, transition from micro to nanoparticles has yielded dramatic changes in physical properties of materials. Large surface area is exhibited for a given volume by nanoparticles because of their high aspect ratios (Luo and Daniel, 2003). The properties of a nanocomposite are seriously subjective to the size scale of its component phases and the grade of mixing between the two phases

Kaolin is very much underutilized raw materials in Malaysia; very few exploration of cheap kaolin is done for raw materials in industrial development. According to Department of Mineral and Geoscience, Malaysia; sizeable reserves of kaolin are found throughout Malaysia (Pui-Kwan, 2013). According to Joint Meteorological Group (JMG), the country has some 112 million tonnes of kaolin reserves located in the states of Perak, Johor, Kelantan, Selangor, Pahang and Sarawak as represented in Figure 1.1. There are 17 active kaolin mines operating mostly located in Bidor and Tapah district in Perak (Aw, 1986). Production of kaolin in 2010 was 530,331 tonnes value at RM 41,670,793 while 2015 was 261,574 tonnes value at RM 24.85 million (Minerals and Geoscience Department Malaysia, 2010).

The study uses Malaysian clay mined in Bidor, in the state of Perak, by KM company. It is located about 145 km north of Kuala Lumpur and 70 km south of lpoh. Kaolin manufacture in the area was initiated on a small scale in the early 1930s, and curently accounts for more than two-thirds of Malaysia's kaolin output of about 50,000 tonnes per annum. Both wet and dry processes are used to produce various grades of kaolin for ceramics, paper, paint, plastics and rubber productions. The most developed kaolin manufactured is of paper-filler grade (Luo and Daniel, 2003).

REFERENCES

Abou-el-sherbini, K. S., Elzahany, E. A. M., Wahba, M. A., Drweesh, S. A., and Youssef, N. S. (2017). Evaluation of some intercalation methods of dimethylsulphoxide onto HCl-treated and untreated Egyptian kaolinite. *Applied Clay Science*, *137*, 33–42.

Adeoye, J. B., Omoleye, J. A., Ojewumi, M. E., and Babalola, R. (2017). Synthesis of Zeolite Y from Kaolin Using Novel Method of Dealumination. *International Journal of Applied Engineering Research*, *12*, 755–760.

Al-Juhani, A. A. (2015). Rheology, mechanical properties, and thermal stability of maleated polyethylene filled with nanoclays. *Journal of Nanomaterials*, *16*, 394.

Al-shameri, A. A., and Rong, L. X. (2009). Characterization and Evaluation of Algaof Kaolin Deposits of Yemen for Industrial Application. *American Journal of Engineering and Applied Science*, *2*, 292–296.

Al-zobaidi, S. (2015). Effects of UV Radiation and Isothermal Crystallization on LDPE / MMT Nanocomposites. *Journal of Engineering and Applied Sciences*, *2*, 1–7.

Amash, A., and Zugenmaier, P. (1997). Thermal and dynamic mechanical investigations on fiber-reinforced polypropylene composites. *Journal of Applied Polymer Science*, *63*, 1143–1154.

Ammar, O., Bouaziz, Y., Haddar, N., and and Mnif, N. (2017). Talc as Reinforcing Filler in Polypropylene Compounds: Effect on Morphology and Mechanical Properties. *Polymer Science*, *3*, 1–7.

Ariffin, A., Ariff, Z. M., and Jikan, S. S. (2010). Effects of kaolin and maleic anhydride contents on melt elasticity and flexural behaviour of polypropylene/ kaolin and unplasticised poly(vinyl chloride)/ kaolin composites. *E-Polymers*, *10*, 1069–1082.

Ariffin, A., Ariff, Z. M., and Jikan, S. S. (2011). Evaluation on nonisothermal

crystallization kinetics of polypropylene/kaolin composites by employing Dobreva and Kissinger methods. *Journal of Thermal Analysis and Calorimetry*, *103*, 171–177.

Ariffin, A., Mansor, A. S., Jikan, S. S., and Ishak, Z. A. M. (2008). Mechanical, Morphological, and Thermal Properties of Polypropylene/Kaolin Composite. Part I. The Effects of Surface-Treated Kaolin and Processing Enhancement. *Journal of Applied Polymer Science*, *108*, 3901–3916.

Aroke, U. O., and El-Nafaty, U. A. (2014). XRF, XRD and FTIR Properties and Characterization of HDTMA-Br Surface Modified Organo-Kaolinite Clay. *International Journal of Emerging Technology and Advanced Engineering*, *4*, 817–825.

ASTM D1238. (2015) Standard test methods for melt flow index (Vol. 17). ASTM, international.

Aw, P. C. (1986). Geology and exploitation of kaolin deposits in the Bidor area, Peninsular Malaysia. In *GEOSEA V Proceedings* (pp. 601--617). Geology Society Malaysia. Bulletin.

Ayaz, M., Daneshpayeh, S., and Noroozi, A. (2016). Enhancing the impact and flexural strength of PP/LLDPE/TiO_2/SEBS nano-composites by using Taguchi methodology. *Composites Science and Technology*, *129*, 61–69.

Ayres, E., Vasconcelos, W. L., and Oréfice, R. L. (2007). Attachment of inorganic moieties onto aliphatic polyurethanes. *Materials Research*, *10*, 119–125.

Baioumy, H., and Ibrahim, A. R. (2012). Mineralogical Variations among the Kaolin Deposits in Malaysia. *Annual International Conference on Geological and Earth Sciences (GEOS 2012) Mineralogical*, 1–2.

Bakar, M. B. A., Leong, Y. W., Ariffin, A., and Ishak, Z. A. M. (2007). Mechanical, flow, and morphological properties of talc-and kaolin-filled polypropylene hybrid composites. *Journal of Applied Polymer Science*, *104*, 434–441.

Bakar, M. B. A., Leong, Y. W., Ariffin, A., and Ishak, Z. A. M. (2008). Effect of Chemical Treatments on the Mechanical, Flow, and Morphological Properties of Talc- and Kaolin-filled Polypropylene Hybrid Composites. *Journal of Applied Polymer Science*, *110*, 2770–2779.

Balakrishna, N. S., Ismail, H., and Othman, N. (2014). Polypropylene/Rattan Powder/Kaolin Hybrid Composites: Processing, Mechanical and Thermal Properties. *Polymer-Plastics Technology and Engineering*, *53*, 451–458.

Barkoula, N. M., Alcock, B., Cabrera, N. O., and Peijs, T. (2008). Fatigue properties of highly oriented polypropylene tapes and all-polypropylene composites. *Polymers and Polymer Composites*, *16*, 101–113.

Bas, A. B., Yilmaz, O., Ibis, A., and Dogu, M. (2016). Melt flow properties of graphite nanoplatelets-filled polypropylene. *Journal of Composite Materials*, *1*, 17–24.

Bas, A. B., Yilmaz, O., Ibis, A., Dogu, M., Kirkkopru, K., and Guner, F. S. (2017). Melt flow properties of graphite nanoplatelets-filled polypropylene. *Journal of Composite Materials*, *51*, 2793–2804.

Bastide, S., Binda, N., and Crespy, A. (1998). Mechanical Behaviour of Polypropylene Composites Containing Fine Mineral Filler: Effect of Filler Surface Treatment. *Composites Science and Technology*, *3538*, 747–752.

Batistella, M., Otazaghine, B., Sonnier, R., Petter, C., and Lopez-Cuesta, J. M. (2016). Fire retardancy of polypropylene/kaolinite composites. *Polymer Degradation and Stability*, *129*, 260–267.

Beecroft, L. L., and Ober, C. K. (1997). Nanocomposite Materials for Optical Applications. *Chemical Materials*, *9*, 1302–1317.

Belver, C., and Banares, M. A. M. V. A. M. (2002). Chemical Activation of a Kaolinite under Acid and Alkaline Conditions. *Chemical Materials*, *14*, 2033–2043.

Benmesli, S., and Riahi, F. (2014). Dynamic mechanical and thermal properties of a chemically modified polypropylene / natural rubber thermoplastic elastomer blend. *Polymer Testing*, *36*, 54–61.

Bertini, F., Canetti, M., Audisio, G., Costa, G., and Falqui, L. (2006). Characterization and thermal degradation of polypropylene-montmorillonite nanocomposites. *Polymer Degradation and Stability*, *91*, 600–605.

Bharadwaj, R. K. (2001). Modeling the Barrier Properties of Polymer-Layered Silicate Nanocomposites. *Macromolecules*, *34*, 9189–9192.

Bhattacharyya, A. R., Sreekumar, T. V., Liu, T., Kumar, S., Ericson, L. M., Hauge, R. H., and Smalley, R. E. (2003). Crystallization and orientation studies in polypropylene/single wall carbon nanotube composite. *Polymer*, *44*, 2373–2377.

Biron, M. (2001). *Thermoplastics and Thermoplastic Composites*. BH Publishers.

Blaiszik, B.J., Kramer, S.L.B., Olugebefola, S.C., Moore, J.S., Sottos, N.R. and

White, S. . (2010). Self-healing polymers and composites. *Annual Review of Materials Research*, *40*, 179–211.

Bledzki, A. K., and Faruk, O. (2004). Effects of the Chemical Foaming Agents , Injection Parameters, and Melt-Flow Index on the Microstructure and Mechanical Properties of Microcellular Injection- Molded Wood-Fiber/Polypropylene Composites. *Journal of Applied Polymer Science*, *97*, 1090.

Blumstein, A., and Malhotra, S. L. (1970). Polymerization of Monolayers. Tacticity of the Insertion Poly(methy1 Methacrylate). *Journal of Polymer Science*, *8*, 1599–1615.

Boborodea, A., and Brookes, A. (2017). Gel permeation chromatography – Atmospheric pressure chemical ionization – Mass spectrometry for characterization of polymer additives. *International Journal of Polymer Analysis and Characterization*, *22*, 210–214.

Boyd, J., West, W. T. J., Wu, S., Takacs, E. S., Vlachopoulos, J., and Thompson, M. R. (2017). Automated image analysis to characterize the melt densification stage of polymer sintering processes. *Polymer Testing*, *60*, 242–249.

Brady, D. G., and Company, P. P. (1976). The Crystallinity of Poly(phenylene Sulfide) and its Effect on Polymer Properties. *Journal of Polymer Science*, *20*, 2541–2551.

Braggs, B., Fornasiero, D., Ralston, J., and St. Smart, R. (1994). The effect of surface modification by an organosilane on the electrochemical properties of kaolinite. *Clays and Clay Minerals*, *42*, 123–136.

Brian S. M. (2004). *An Introduction to Materials Engineering and Science*. Canada: John Willey and Sons, Inc.Hoboken, New Jersey.

Browska, I. (2013). *Polyolefin nanocomposite with different types of nanofillers*. Department of Industrial Engineering, Doctoral School in Materials Science and Engineering, University of Trento, Italy.

Cabedo, L., Villanueva, M. P., Lagarón, J. M., and Giménez, E. (2017). Development and characterization of unmodified kaolinite/EVOH nanocomposites by melt compounding. *Applied Clay Science*, *135*, 300–306.

Campbell Jr F.C,. (2003). *Manufacturing processes for advanced composites*. *Elsevier*, 1(7) 257-787

Carlos, J., Segura, F., Esteban, V., Cruz, R., Jesús, J. De, Bueno, and Legorreta, F.

(2017). Characterization and electrochemical treatment of a kaolin. *Applied Clay Science*, *146*, 264–269.

Carolan, D., Ivankovic, A., Kinloch, A. J., Sprenger, S., and Taylor, A. C. (2017). Toughened carbon fibre-reinforced polymer composites with nanoparticle-modified epoxy matrices. *Journal of Materials Science*, *52*, 1767–1788.

Cervantes-Uc, J. M., Espinosa, J. I. M., Cauich-Rodríguez, J. V., Ávila-Ortega, A., Vázquez-Torres, H., Marcos-Fernández, A., and Román, J. S. (2009). TGA/FTIR studies of segmented aliphatic polyurethanes and their nanocomposites prepared with commercial montmorillonites. *Polymer Degradation and Stability*, *94*, 1666–1677.

Chaka, K. T., Fambri, L., and Govindan, N. (2017). Kaolinite/Polypropylene Nanocomposites. Part 3: 3D Printing. *International Research Journal of Engineering and Technology*, *4*, 132–147.

Chang, C. J., Chiang, T., and Shi, D. (2017). Effect of surface modified kaolin on properties of polypropylene grafted maleic anhydride. *Results in Physics*, *7*, 27–35.

Chang, R. (1996). *Essential chemistry*. McGraw-Hill Science, Engineering and Mathematics.

Chen, X., Ma, C., and Jiao, C. (2016). Enhancement of flame-retardant performance of thermoplastic polyurethane with the incorporation of aluminum hypophosphite and iron-graphene. *Polymer Degradation and Stability*, *129*, 275–285.

Cheng, H., Liu, Q., Yang, J., Ma, S., and Frost, R. L. (2012). The thermal behavior of kaolinite intercalation complexes-A review. *Thermochimica Acta*, *545*, 1–13.

Cheng, H., Liu, Q., Zhang, J., Yang, J., and Frost, R. L. (2010). Delamination of kaolinite-potassium acetate intercalates by ball-milling. *Journal of Colloid and Interface Science*, *348*, 355–359.

Chrissafis, K., Paraskevopoulos, K. M., Tsiaoussis, I., and Bikiaris, D. (2009). Comparative study of the effect of different nanoparticles on the mechanical properties, permeability, and thermal degradation mechanism of HDPE. *Journal of Applied Polymer Science*, *114*, 1606–1618.

Cornelia, G., and Schuit, A. (1941). Isomerisation of hydrocarbons. United States Patent Office 2,265,870.

Cristina-Elisabeta, P., Adriana, S., George, P., Ion, D., Anton, F., Ecaterina, A., and

Georgeta, V. (2015). Mechanical Properties of Nanofilled Polypropylene Composites. *Incas Bulletin*, *7*, 113–121.

Cristina, B., Ion, D., Adriana, S., and George, P. (2012). Nanocomposites as Advanced Materials for Aerospace Industry. *Incas Bulletin*, *4*, 57–72.

Cruz, M. D. R., and Duro, F. I. F. (1999). New data on the kaolinite-potassium acetate complex. *Clay Minerals*, *34*, 565–577.

Dabrowska, I., Fambri, L., Batistella, M., and Lopez-Cuesta, J. M. (2014). Compounding and spinning of polypropylene nanocomposites with kaolinite. In *16th European Conference on Composite Materials, ECCM 2014* (pp. 22–26).

Dai, J. (1999). Surface modification of clays and clay–rubber composite. *Applied Clay Science*, *15*, 51–65.

Dang, Z. M., Yuan, J. K., Zha, J. W., Zhou, T., Li, S. T., and Hu, G. H. (2012). Fundamentals, processes and applications of high-permittivity polymer-matrix composites. *Progress in Materials Science*, *57*, 660–723.

De Carvalho, A. J. F., Curvelo, A. A. S., and Agnelli, J. A. M. (2001). A first insight on composites of thermoplastic starch and kaolin. *Carbohydrate Polymers*, *45*, 189–194.

De Medeiros Albano, F., Pizzolato, M., and Rodrigues, T. M. (2017). Certification of the Melt Flow Index of a Polymeric Reference Material Based on a Proficiency Testing Scheme. *MAPAN-Journal of Metrology Society of India*, *32*, 149–154.

Deenadayalan, E., Vidhate, S. and Lele, A. (2006). Nanocomposites of polypropylene impact copolymer and organoclays: role of compatibilizers. *Polymer International*, *55*, 1270–1276.

Delhez, R., Keijser, T. H., Mittemeijer, E. J., and Z.Fresenius. (1982). Determinationof crystallite size and lattice distortions through X-ray diffraction line profile analysis,. *Fresenius' Journal of Analytical Chemistry*, *312*, 1–16.

Delva, L., Ragaert, K., Degrieck, J., and Cardon, L. (2014). The effect of multiple extrusions on the properties of montmorillonite filled polypropylene. *Polymers*, *6*, 2912–2927.

Demirba, Ö., and Ulus, O. (2017). Synthesis and Characterization of Polypropylene and CTAB Modified Diatomite Composites. *International Research Journal of Pure and Applied Chemistry*, *13*, 17–21.

Detellier, C., and Letaief, S. (2013). *Kaolinite-polymer nanocomposites*. *Developments in Clay Science* (2nd ed., Vol. 5). Elsevier Ltd.

Dias, B. Z., and Alvarez, C. E. (2017). Mechanical properties: wood lumber versus plastic lumber and thermoplastic composites. *Ambiente Construído*, *17*, 201–219.

Díez-Pascual, A. M., and Naffakh, M. (2013). Polypropylene/glass fiber hierarchical composites incorporating inorganic fullerene-like nanoparticles for advanced technological applications. *ACS Applied Materials and Interfaces*, *5*, 9691–9700.

Djoufac, W., Kamga, R., Figueras, F., Njopwouo, D. (2007). Acid activation and bleaching capacity of some Cameroonian smectite soil clays. *Applied Clay Science*, *37*, 149–156.

Dong, Q., Chen, Q., Yang, W., Zheng, Y., Liu, X., Li, Y., and Yang, M. (2008). Thermal Properties and Flame Retardancy of Polycarbonate / Hydroxyapatite Nanocomposite. doi:10.1002/app

Dong, Y., and Bhattacharyya, D. (2008). Effects of clay type, clay/compatibiliser content and matrix viscosity on the mechanical properties of polypropylene/organoclay nanocomposites. *Composites Part A: Applied Science and Manufacturing*, *39*, 1177–1191.

Du, B., Tsui, O. K. C., Zhang, Q., and He, T. (2001). Study of Elastic Modulus and Yield Strength of Polymer Thin Films Using Atomic Force Microscopy. *Journal of Applied Polymer Science*, *7*, 3286–3291.

Ebrahimi, I., and Gashti, M. P. (2016). Chemically reduced versus photo-reduced clay-Ag-polypyrrole ternary nanocomposites: Comparing thermal, optical, electrical and electromagnetic shielding properties. *Materials Research Bulletin*, *83*, 96–107.

Effah, B., Van Reenen, A., and Meincken, M. (2015). Characterisation of the Interfacial Adhesion of the Different Components in Wood–Plastic Composites with AFM. *Springer Science Reviews*, *3*, 97–111.

Ene, A., Boşneaga, A., and Georgescu, L. (2010). Determination of heavy metals in soils using XRF technique. *Romanian Journal of Physics.*, *55*, 815–820.

EP Giannelis. (1998). Polymer-Layered Silicate Nanocomposites: Synthesis, Properties and Applications. Applied Organometallic Chemistry. *Applied Organometallic Chemistry*, *12*, 675–80.

Faridmehr, I., Hanim Osman, M., Bin Adnan, A., Farokhi Nejad, A., Hodjati, R., and Amin Azimi, M. (2014). Correlation between Engineering Stress-Strain and

True Stress-Strain Curve. *American Journal of Civil Engineering and Architecture*, *2*, 53–59.

Faulkner, D.L. and Schmidt, L. R. (1977). Glass bead-filled polypropylene part I: Rheological and mechanical properties. *Polymer Engineering and Science*, *17*, 657–665.

Feldman, D. (2016). Polymer nanocomposites in building, construction. *Journal of Macromolecular Science, 53 Part A*, 55–62.

Feng, X., Zhang, G., Zhuo, S., Jiang, H., Shi, J., Li, F., and Li, H. (2016). Dual responsive shape memory polymer/clay nanocomposites. *Composites Science and Technology*, *129*, 53–60.

Friedrich, F. (2004). *Spectroscopic investigations of delaminated and intercalated phyllosilicates*. Bauingenieur-, Geo- und Umweltwissenschaften der Universität Fridericiana zu Karlsruhe (TH).

Frost, R.. Kristof J, E. Mako, E. Horvath,. (2003). Polymer science *Spectrochim. Acta A:*, *59*, 1183.

Frost, R. ., Makó, É., Kristóf, J., and Kloprogge, J. (2002)a. Modification of kaolinite surfaces through mechanochemical treatment—a mid-IR and near-IR spectroscopic study. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *58*, 2849–2859.

Frost, R. L., Kristof, J., Mako, E., and Martens, W. N. (2002)b. Modification of the hydroxyl surface of kaolinite through mechanochemical treatment followed by intercalation with potassium acetate. *Langmuir*, *18*, 6491–6498.

Frost, R. L., Mako, Ä., Kloprogge, J. T., and Veszpre, H. (2001). Modification of Kaolinite Surfaces by Mechanochemical Treatment, 4731–4738.

Gacitua, W., Ballerini, A., and Zhang, J. (2005). Polymer Nanocomposites: Synthetic and Natural Fillers a Review. *Maderas. Ciencia Y Tecnología*, *7*, 159–178.

Galgali, G., Ramesh, C., and Lele, A. (2001). Rheological study on the kinetics of hybrid formation in polypropylene nanocomposites. *Macromolecules*, *34*, 852–858.

García-Serrano, J., Galindo, A. G., and Pal, U. (2004). Au-Al2O3 nanocomposites: XPS and FTIR spectroscopic studies. *Solar Energy Materials and Solar Cells*, *82*, 291–298.

Gardolinski Luiz Pereira; de Souza, Gabriel Pinto; Wypych, Fernando, J. E. R., Gardolinski, J. E., Ramos, L. P., de Souza, G. P., and Wypych, F. (2000).

Intercalation of benzamide into kaolinite. *Journal of Colloid and Interface Science*, *221*, 284–290.

Garg, H., and Singh, R. (2016). Investigations for melt flow index of Nylon6-Fe composite based hybrid FDM filament. *Rapid Prototyping Journal*, *22*, 338–343.

Gashti, M. P., and Eslami, S. (2012). Structural, optical and electromagnetic properties of aluminum-clay nanocomposites. *Superlattices and Microstructures*, *51*, 135–148.

Gashti, M. P., Hajiraissi, R., and Gashti, M. P. (2013). Morphological, optical and electromagnetic characterization of polybutylene terephthalate/silica nanocomposites. *Fibers and Polymers*, *14*, 1324–1331.

Gates, W.P., Slade, P.G., Manceau, A. and Lanson, B. (2002). Site occupancies by iron in nontronites. *Clays and Clay Minerals*, *60*, 223–239.

George, T. S., Krishnan, A., Anjana, R., and George, K. E. (2013). Studies on Nano Kaolin Clay Reinforced PS-HDPE Nanocomposites. *Indian Journal of Advances in Chemical Science*, *1*, 201–206.

Giannelis, E. P. (1998). Polymer-layered silicate nanocomposites: Synthesis, properties and applications. *Applied Organometallic Chemistry*, *12*, 675–680.

Gibson, R. . (2010). A review of recent research on mechanics of multifunctional composite material. *Composite Structures*, *92*, 2793–2810.

Gilman, J. W., Jackson, C. L., Morgan, B., Harris, R., Giannelis, E. P., and Wuthenow. (2000). Flammability Properties of Polymer - Layered-Silicate. *Chemical Technology*, 1866–1873.

Glynn, P. A. R., and Hoff, B. M. E. Van Der. (1974). Polymerization of Vinyl Monomers on Mineral Surfaces; A Novel Method of Preparing Reinforcing Fillers. *Journal of Macromolecular Science: Part A - Chemistry: Pure and Applied Chemistry*, *8*, 1653–1664.

Golebiewski, J., and Galeski, A. (2007). Thermal stability of nanoclay polypropylene composites by simultaneous DSC and TGA. *Composites Science and Technology*, *67*, 3442–3447.

Gomaa, E. (2009). Study of Electrical, Mechanical and Nanoscale Free-Volume Properties of NBR and EPDM Rubber Reinforced by Bentonite or Kaolin, 1825–1838.

Grim, R. E. (1953). *Clay Mineralogy* (Vol. 76).]llinois: McGraw-Hill Book

Company, Inc. United States of America.

Guessoum, M., Nekkaa, S., Fenouillot-Rimlinger, F., and Haddaoui, N. (2012). Effects of kaolin surface treatments on the thermomechanical properties and on the degradation of polypropylene. *International Journal of Polymer Science*, *2012*, 1–9.

Hajiraissi, R., and Parvinzadeh, M. (2011). Preparation of polybutylene terephthalate/silica nanocomposites by melt compounding: Evaluation of surface properties. *Applied Surface Science*, *257*, 8443–8450.

Han, C.D., Van Den Weghe, T., Shete, P. and Haw, J. R. (1981). Effects of coupling agents on the rheological properties, processability, and mechanical properties of filled polypropylene. *Polymer Engineering and Science*, *21*, 196–204.

Hao, W., Li, W., Yang, W., and Shen, L. (2011). Effect of silicon nitride nanoparticles on the crystallization behavior of polypropylene. *Polymer Testing*, *30*, 527–533.

Haraguchi, K., Uyama, K., and Tanimoto, H. (2011). Self-healing in Nanocomposite Hydrogels. *Macromolecular rapid communications*, *32*(16), 1253-1258.

Hasegawa, N., Kawasumi, M., Kato, M., Ukudi, A., and Okada, A. (1998). Preparation and mechanical properties of polypropylene-clay hybrids using a maleic-anhydride grafted polypropylene oligomer. *Journal of Applied Polymer Science.*, *67*, 87–92.

Ható, Z., Makó, É., and Kristóf, T. (2013). Molecular simulation study of kaolinite intercalation. *12th Joint European Thermodynamics Conference Brescia*, *41*, 2013.

Hegde, R. (2009). *Structure and properties of nanoclay reinforced polymer films, fibers and nonwovens*. *Doctoral Dissertations*. University of Tennessee, Knoxville.

Hegde, R. R., Bhat, G. S., Spruiell, J. E., and Benson, R. (2013). Structure and properties of polypropylene-nanoclay composites. *Journal of Polymer Research*, *20*, 323–346.

Henrique, P., Camargo, C., Satyanarayana, K. G., and Wypych, F. (2009). Nanocomposites : Synthesis, Structure , Properties and New Application Opportunities. *Materials Research*, *12*, 1–39.

Hernández, K. A. H. (2016). Polymer-Clay Nanocomposites and Composites: Structures, Characteristics, and their Applications in the Removal of Organic

Compounds of Environmental Interest. *Medicinal Chemistry*, *6*, 201–210.

Herrmann, A. S., Stieglitz, A., Brauner, C., Peters, C., and Schiebel, P. (2013). Polymer Matrix Composites. *Structural Materials and Processes in Transportation*, 257–302.

Hinsken, H., Moss, S., Pauquet, J. R., and Zweifel, H. (1991). Degradation of polyolefins during melt processing. *Polymer Degradation and Stability*, *34*, 279–293.

Horváth, E., Kristóf, J., Frost, R. L., Jakab, E., Makó, É., and Vágvölgyi, V. (2005). Identification of superactive centers in thermally treated formamide-intercalated kaolinite. *Journal of Colloid and Interface Science*, *289*, 132–138.

Hosseini, M. R., Pazouki, M., Ranjbar, M., and Habibian, M. (2007). Bioleaching of iron from highly contaminated Kaolin clay by Aspergillus niger, *37*, 251–257.

Hu, P., and Yang, H. (2013). Insight into the physicochemical aspects of kaolins with different morphologies. *Applied Clay Science*, *74*, 58–65.

Hu, P., Yang, H., and Ouyang, J. (2012). Synthesis and characterization of Sb-SnO_2 kaolinites nanoparticles. *Applied Clay Science*, *55*, 151–157.

Hu, S. F., Zhu, X. B., Hu, W., Yan, L., and Cai, C. (2013). Crystallization behaviors and foaming properties of diatomite-filled polypropylene composites. *Polymer Bulletin*, *70*, 517–533.

Hussain, F., Hojjati, M., Okamoto, M., and Gorga, R. E. (2006). Review article: Polymer-matrix Nanocomposites, Processing, Manufacturing, and Application: An Overview. *Journal of Composite Materials*, *40*, 1511–1575.

Indian Bureau of Mines. (2016). Indian Minerals Yearbook 2015. *Indian Minerals Yearbook 2015 (Part-III: Mineral Reviews)*, *54th Editi*, 1–9.

Ishak, M. R., Sapuan, S. M., Leman, Z., Rahman, M. Z. A., Anwar, U. M. K., and Siregar, J. P. (2013). Sugar palm (Arenga pinnata): Its fibres, polymers and composites. *Carbohydrate Polymers*, *91*, 699–710.

ISO 13320 (1999). Particle size analysis-Laser diffractio methods, part 1. International Organisation for Standardisation.

ISO 1133 (2011). Detrmination of the melt mass flow rate(MFR) and melt volume-flow rate(MVR) of thermoplastics. Part 1. International Organisation for Standardisation.

Jafarzadeh, S., Alias, A. K., Ariffin, F., Mahmud, S., and Najafi, A. (2016). Preparation and characterization of bionanocomposite films reinforced with

nano kaolin. *Journal of Food Science and Technology*, *53*, 1111–1119.

Jang, K.-S. (2016). Mineral filler effect on the mechanics and flame retardancy of polycarbonate composites: talc and kaolin. *E-Polymers*, *16*, 379–386.

Jasmund, K., and G, L. (1993). Structure, properties, application and application in industry and environment. *Clay Minerals and Clays*.

Jikan, S. S., Ariff, Z. M., and Ariffin, A. (2010). Influence of filler content and processing parameter on the crystallization behaviour of PP/kaolin composites. *Journal of Thermal Analysis and Calorimetry*, *102*, 1011–1017.

Jillavenkatesa, A., Dapkunas, S. J., and Lum. (2001). Particle Size Characterization. *NIST Special Publication*, *960*, 164.

Josef, J. (1998). *Mineral fillers in thermoplastics: Filler Manufacture and Characterisation*. Czech Republic: Advances in Polymer Science.

Kaempfer, D., Thomann, R., and Mülhaupt, R. (2002). Melt compounding of syndiotactic polypropylene nanocomposites containing organophilic layered silicates and in situ formed core/shell nanoparticles. *Polymer*, *43*, 2909–2916.

Kang, J., Wang, B., Peng, H., Chen, J., Cao, Y., Li, H., and Xiang, M. (2014). Investigation on the structure and crystallization behavior of controlled-rheology polypropylene with different stereo-defect distribution. *Polymer Bulletin*, *71*, 563–579.

Kang, J., Yang, F., Chen, J., Cao, Y., and Xiang, M. (2017). Influences of molecular weight on the non-isothermal crystallization and melting behavior of β-nucleated isotactic polypropylene with different melt structures. *Polymer Bulletin*, *74*, 1461–1482.

Karamane, M., Raihane, M., Tasdelen, M. A., Uyar, T., Lahcini, M., Ilsouk, M., and Yagci, Y. (2017). Preparation of fluorinated methacrylate/clay nanocomposite via *in-situ* polymerization: Characterization, structure, and properties. *Journal of Polymer Science Part A: Polymer Chemistry*, *55*, 411–418.

Kashiwagi, T., Grulke, E., Hilding, J., Harris, R., Awad, W., and Douglas, J. (2002). Thermal degradation and flammability properties of poly(propylene)/carbon nanotube composites. *Macromolecular Rapid Communications*, *23*, 761–765.

Kausar, A., Rafique, I., and Muhammad, B. (2017). Aerospace application of polymer nanocomposite with carbon nanotube, graphite, graphene oxide, and nanoclay. *Polymer-Plastics Technology and Engineering*, *56*(13), 1438-1456.

Kawasumi, M., Hasegawa, N., Kato, M., Usuki, A. and Okada, A. (1997).

Preparation and mechanical properties of polypropylene− clay hybrids. *Macromolecules*, *30*, 6333–6338.

Kessler, M. R. (2007). Self-healing: a new paradigm in materials design. Proceedings of the Institution of Mechanical Engineers. *Part G:Journal of Aerospace Engineering*, *221*, 479–495.

Kessler, M. R. (2012). Polymer Matrix Composites: A Perspective for a Special Issue of Polymer Reviews. *Polymer Reviews*, *52*, 229–233.

Khang, V. C., Korovkin, M. V., and Ananyeva, L. G. (2016). Identification of clay minerals in reservoir rocks by FTIR spectroscopy. *IOP Conference Series: Earth and Environmental Science*, *43*, 12004.

Khoshkava, V. (2013). *Polypropylene (PP) nanocomposites incorporating nanocrystalline cellulose (NCC)*. McGill Univeristy, Montreal, Canada.

Kibanova, D., Cervini-Silva, J., and Destaillats, H. (2009). Efficiency of clay - TiO_2 nanocomposites on the photocatalytic elimination of a model hydrophobic air pollutant. *Environmental Science and Technology*, *43*, 1500–1506.

Kim, K. J., White, J. L., Eun Shim, S., and Choe, S. (2004). Effects of stearic acid coated talc, CaCO3, and mixed talc/$CaCO_3$ particles on the rheological properties of polypropylene compounds. *Journal of Applied Polymer Science*, *95*, 2105–2113.

Kim, K.-J., White, J. L., Eun Shim, S., and Choe, S. (2004). Effects of stearic acid coated talc, $CaCO_3$, and mixed talc/$CaCO_3$ particles on the rheological properties of polypropylene compounds. *Journal of Applied Polymer Science*, *93*, 2105–2113.

Komori, Y., Sugahara, Y., and Kuroda, K. (2011). A kaolinite-NMF-methanol intercalation compound as a versatile intermediate for further intercalation reaction of kaolinite. *Journal of Materials Research*, *13*, 930–934.

Koo, J. H. (2006). *Polymer nanocomposites: Processing, Characterisation and Applications*. (S. E. O. Manasreh, Ed.). McGraw-Hill Nanoscience and Technology Series Series.

Kotal, M., and Bhowmick, A. K. (2015). Polymer nanocomposites from modified clays: Recent advances and challenges. *Progress in Polymer Science*, *51*, 127–187.

Kozak, M., and Domka, L. (2004). Adsorption of the quaternary ammonium salts on montmorillonite. *Journal of Physics and Chemistry of Solids*, *65*, 441–445.

Krishnamoorti, R., and Giannelis, E. P. (1997). Rheology of End-Tethered Polymer Layered Silicate Nanocomposites. *Macromolecules*, *30*, 4097–4102.

Krishnan, A. K. and George, K. E. (2014). Polymer blend nanocomposites: effect of mercapto silane modified kaolin clay on the thermal properties of Polypropylene/Polystyrene blend. *Polymers for Advanced Technologies*, *25*, 955–962.

Krishnan, A. K., George, T. S., Anjana, R., Joseph, N., and George, K. E. (2013). Effect of modified kaolin clays on the mechanical properties of polypropylene/polystyrene blends. *Journal of Applied Polymer Science*, *127*, 1409–1415.

Kristof, J., Frost, R. L., Felinger, A., and Minka, J. (1997). FTIR spectroscopic study of intercalated kaolinite. *Journal of Molecular Structure*, *2860*, 119–122.

Kumar, S., Panda, A. K., and Singh, R. K. (2013). Preparation and Characterization of Acids and Alkali Treated Kaolin Clay. *Bulletin of Chemical Reaction Engineering and Catalysis*, *8*, 61–69.

Lagaly, G., and Beneke, K. (1991). Intercalation and exchange reactions of clay minerals and non-layer compounds. *Colloid and Polymer Science*, *1211*, 1198–1211.

Ledoux, R. L., Laval, U., and White, J. L. (1966). Infrared Studies of Hydrgen Interaction between Kaolinite Surfaces and Intercalated Potassium Acetate, Hydrazine, and Urea. *Jouranal of Colloid and Interface Science*, *21*.

Lee, Kyung Min, and C. D. H. (2003). Rheology of organoclay nanocomposites: effects of polymer matrix/organoclay compatibility and the gallery distance of organoclay. *Macromolecules*, *36*, 7165–7178.

Lee, G. W., Jagannathan, S., Chae, H. G., Minus, M. L., and Kumar, S. (2008). Carbon nanotube dispersion and exfoliation in polypropylene and structure and properties of the resulting composites. *Polymer*, *49*, 1831–1840.

Lee Kang-Nyung. (2000). *Effect of Chemical Treatment on III-Nitride Surface Characteristics*. University of Florida. Phd Thesis.

Lee S.H, Kim J.E, Song H.H, K. S. (2005). Thermal properties of maleated polyethylene/layered silicate nanocomposites. *International Journal of Thermophysics*, *25*, 1585–95.

Leong, Y. W., Bakar, M. B. A., Ishak, Z. A. M., Ariffin, A., and Pukanszky, B. (2003). Comparison of the Mechanical Properties and Interfacial Interactions

Between Talc, Kaolin, and Calcium Carbonate Filled Polypropylene Composites. *Journal of Applied Polymer Science*, *91*, 3315–3326.

Leroux, F., and Besse, J. (2001). Polymer Interleaved Layered Double Hydroxide : A New Emerging Class of Nanocomposites Polymer Interleaved Layered Double Hydroxide : A New Emerging Class of Nanocomposites. *Chemistry of Materials*, 3507–3515.

Lertwimolnun, W., and Vergnes, B. (2005). Influence of compatibilizer and processing conditions on the dispersion of nanoclay in a polypropylene matrix. *Polymer*, *46*, 3462–3471.

Letaief, S., and Christian, D. (2009). Functionalization of the interlayer surfaces of kaolinite by alkylammonium groups from ionic liquids. *Clays and Clay Minerals*, *57*, 638–648.

Letaief, S., and Detelleir, C. (2008)a. Ionic liquids-Kaolinite nanostructured materials. Intercalation of pyrrolidinium salts. *Clays and Clay Minerals*, *56*, 82–89.

Letaief, S., and Detellier, C. (2008)b. Interlayer grafting of glycidol (2,3-epoxy-1-propanol) on kaolinite. *Canadian Journal of Chemistry*, *86*, 1–6.

Letaief, S., Elbokl, T. A., and Detellier, C. (2006). Reactivity of ionic liquids with kaolinite: Melt intersalation of ethyl pyridinium chloride in an urea-kaolinite pre-intercalate. *Journal of Colloid and Interface Science*, *302*, 254–258.

Li, G., Zhao, Y., and Pang, S. (1999). Analytical modeling of particle size and cluster effects on particulate-filled composite. *Materials Science and Engineering: A*, *271*, 43–52.

Li, X., Liu, Q., Cheng, H., Zhang, S., and Frost, R. L. (2015). Mechanism of kaolinite sheets curling via the intercalation and delamination process. *Journal of Colloid and Interface Science*, *444*, 74–80.

Liang, J. Z. (2013). Reinforcement and quantitative description of inorganic particulate-filled polymer composites. *Composites Part B: Engineering*, *51*, 224–232.

Liang, J. Z., and Ness, J. N. (1997). Studies on melt flow properties of low density and linear low density polyethylene blends in capillary extrusion. *Polymer Testing*, *16*, 173–184.

Lima, P. E. A., Romulus.Angelica, and Roberto F. Neves. (2017). Dissolution kinetics of Amazonian metakaolin in hydrochloric acid. *Clay Minerals*, *52*, 75–

82.

Lin, F., Xiang, Y., and Shen, H. (2017). Temperature dependent mechanical properties of graphene reinforced polymer nanocomposites – A molecular dynamics simulation. *Composites Part B: Engineering*, *111*, 261–269.

Liu, X., Hu, N., Zhang, H., Ha, C., and Yang, Z. (2005). Effects of modified kaolin on the crystallization property of PP/Kaolin nanocomposites. *Science in China Series B: Chemistry*, *48*, 326–333.

Liu, X., and Wu, Q. (2001). PP/clay nanocomposites prepared by grafting-melt intercalation. *Polymer*, *42*, 10013–10019.

Luo, J. J., and Daniel, I. M. (2003). Characterization and modeling of mechanical behavior of polymer/clay nanocomposites. *Composites Science and Technology*, *63*, 1607–1616.

Lv, S., Zhou, W., Li, S., and Shi, W. (2008). A novel method for preparation of exfoliated UV-curable polymer/clay nanocomposites. *European Polymer Journal*, *44*, 1613–1619.

Macêdo Neto, J. C. De, and Lona, L. M. F. (2012). Characterization by TEM of kaolinite to production of polymer nanocomposites. *AIP Conference Proceedings*, *1437*, 69–71.

Mago, G., Kalyon, D. M., Jana, S. C., and Fisher, F. T. (2010). Polymer nanocomposite processing, characterization, and applications. *Journal of Nanomaterials*, *2010*, 2–4.

Mahdavi, F., Abdul, R., and Khanif, Y. (2014). Intercalation of urea into kaolinite for preparation of controlled release fertilizer. *Chemical Industry and Chemical Engineering Quarterly*, *20*, 207–213.

Mahmood, I. A. (2017). Characteristics and Properties of Epoxy / Polysulfide Blend Matrix Reinforced by Short Carbon and Glass Fibers, *20*, 80–87.

Maiti, P., Batt, C. A., and Giannelis, E. P. (2007). New biodegradable polyhydroxybutyrate/layered silicate nanocomposites. *Biomacromolecules*, *8*, 3393–3400.

Maiti S. N. and Lopez B. H. Centre. (1992). Tensile Properties of Polypropylene/ Kaolin Composites. *Journal of Applied Polymer Science*, *44*, 353–360.

Makhlouf, A., Satha, H., Frihi, D., Gherib, S., and Seguela, R. (2016). Optimization of the crystallinity of polypropylene/submicronic-talc composites: The role of filler ratio and cooling rate. *Express Polymer Letters*, *10*, 237–247.

Makó, É., Kristóf, J., Horváth, E., and Vágvölgyi, V. (2009). Kaolinite-urea complexes obtained by mechanochemical and aqueous suspension techniques-A comparative study. *Journal of Colloid and Interface Science*, *330*, 367–373.

Makó, É., Senkár, Z., Kristóf, J., and Vágvölgyi, V. (2006). Surface modification of mechanochemically activated kaolinites by selective leaching, *Langmuir 294*, 362–370.

Mallakpour, S., and Khadem, E. (2014). Recent development in the synthesis of polymer nanocomposites based on nano-alumina. *Progress in Polymer Science*, *51*, 74–93.

Malnati, P. (2009). ECO Elise concept: Lean, speedy and green. *Composites Technology*, *8*, 46–48.

Malvern Instruments Ltd. (2012). A basic guide to particle characterization. *Inform White Paper*, 1–26.

Matadi, R., Makradi, A., Ahzi, S., Sieffert, J. G., Etienne, S., Rush, and Bouquey, M. (2009). Preparation, structural characterization, and thermomechanical properties of poly(methyl methacrylate)/organoclay nanocomposites by melt intercalation. *Journal of Nanoscience and Nanotechnology*, *9*, 2923–2930.

Matějka, V., and Neuwirthová, L. (2014). Effect of Kaolinite Exfoliation on the Photocatalytic Properties of Kaolinite/TiO_2 Composite. *Advanced Science, Engineering and Medicine*, *6*, 490–494.

Matusik, J., Scholtzová, E., and Tunega, D. (2012). Influence of synthesis conditions on the formation of a Kaolinitemethanol complex and simulation of its vibrational spectra. *Clays and Clay Minerals*, *60*, 227–239.

Mauldin, T.C., Haman, K., Sheng, X., Henna, P., Larock, R.C. and Kessler, M. (2008). Ring-opening metathesis polymerization of a modified linseed oil with varying levels of crosslinking. *Journal of Polymer Science Part A: Polymer Chemistry*, *46*, 6851–6860.

Maver, U., Maver, T., Persin, Z., Mozetic, M., Vesel, P., Gaberscek, M., and Stana-Kleinschek, K. (2013). Polymer characterization with the atomic force microscope. *Polymer Science*, 113–132.

Mclauchlin, A., Bao, X., and Zhao, F. (2011). Organoclay polybutylene terephthalate nanocomposites using dual surfactant modi fi ed montmorillonite prepared by the masterbatch method. *Applied Clay Science*, *53*, 749–753.

Meola, C., Boccardi, S., Boffa, N. D., Ricci, F., Simeoli, G., Russo, P., and

Carlomagno, G. M. (2016). New perspectives on impact damaging of thermoset- and thermoplastic-matrix composites from thermographic images. *Composite Structures*, *152*, 746–754.

Meziane, O., Bensedira, A., Guessoum, M., and Haddaoui, N. (2016). Polypropylene-Modified Kaolinite Composites: Effect of Chemical Modification on Mechanical, Thermal and Morphological Properties. *Journal of Fundamental and Applied Sciences*, *8*, 494–509.

Meziane, O., Bensedira, A., Guessoum, M., and Haddaoui, N. (2017). Preparation and Characterization of Intercalated Kaolinite with : Urea, Dimethyl formamide and an Alkylammonium Salt Using Guest Displacement Reaction, *Journal of Materials and Environmental Sciences 8*, 3625–3635.

Minerals and Geoscience Department Malaysia. (2010). *Malaysian Minerals Yearbook 2010*.

Miranda-Trevino, J. C., and Coles, C. A. (2003). Kaolinite properties, structure and influence of metal retention on pH. *Applied Clay Science*, *23*, 133–139.

Mitchell, B. (2004). *An introduction to materials engineering and science for chemical and materials engineers*. *John Wiley and Sons*.

Mitrović, A., and Zdujić, M. (2013). Mechanochemical treatment of Serbian kaolin clay to obtain a highly reactive pozzolana. *Journal of the Serbian Chemical Society*, *78*, 579–590.

Mittal, V. (2009). Polymer layered silicate nanocomposites: A review. *Materials*, *2*, 992–1057.

Mohsen, Q., and El-maghraby, A. (2010). Characterization and assessment of Saudi clays raw material at different area. *Arabian Journal of Chemistry*, *3*, 271–277.

Mondal, S., Mondal, B., Dey, A., and Mukhopadhyay, S. S. (2012). Studies on Processing and Characterization of Hydroxyapatite Biomaterials from Different Bio Wastes. *Journal of Minerals and Materials Characterization and Engineering*, *11*, 55–67.

Montanari, G. C., Teyssedre, G., Laurent, C., Kaempfer, D., and Mulhaupt, R. (2004). Investigating Charge Trapping Behaviour of Nanocomposite Isotactic and Syndiotactic Polypropylene Matrix. *Solid Dielectrics, 2004. ICSD 2004. Proceedings of the 2004 IEEE International Conference on*, *2*, 836–839 Vol.2.

Morgan, B., and Gilman, J. W. (2003). Characterization of polymer-layered silicate (Clay) nanocomposites by transmission electron microscopy and X-Ray

diffraction : A comparative study. *Appleid Polymer Science*, *87*, 1329–1338.

Moseley, J. M., Miller, D. C., Kempe, M. D., Kurtz, S. R., TamizhMani, G., and Sakurai, K. (2011). Use of Melt Flow Rate Test in Reliability Study of Thermoplastic Encapsulation Materials in Photovoltaic Modules. *Material science forum* 7, 235-345

MS ISO 527A (1994). Malaysian standard. Plastics- Determination of tensile properties (Vol 1).Standard and industrial research institute of Malaysia.

MS ISO 179 (2002). Plastics-determination of charpy impact properties. Part 1. Non-intrumented impact test. Department of Standards Malysia.

Muksing, N., Coiai, S., Conzatti, L., Passaglia, E., Magaraphan, R., and Ciardelli, F. (2010). Morphology Development and Stability of Polypropylene/Organoclay Nanocomposites. *Journal of Nnanoscience and Nanotechnology*, *10*, 5814–5825.

Müller, P., Renner, K., Móczó, J., Fekete, E., and Pukánszky, B. (2014). Thermoplastic starch / wood composites : Interfacial interactions and functional properties. *Carbohydrate Polymers*, *102*, 821–829.

Murakami, J., Itagaki, T., and Kuroda, K. (2004). Synthesis of kaolinite-organic nanohybrids with butanediols. *Solid State Ionics*, *172*, 279–282.

Murray, H. H. (2000). Traditional and new applications for kaolin, smectite, and palygorskite : A general overview. *Applied Clay Science*, *17*, 207–221.

Museum, M. (1991). Composite material. *Composites*, *22*, 253–257.

Nafchi, H. R., Abdouss, M., Najafi, S. K., Gargari, R. M., and Mazhar, M. (2015). Effects of nano-clay particles and oxidized polypropylene polymers on improvement of the thermal properties of wood plastic composite. *Maderas. Ciencia Y Tecnología*, *17*, 45–54.

Navidfar, A., Azdast, T., and Karimzad Ghavidel, A. (2016). Influence of processing condition and carbon nanotube on mechanical properties of injection molded multi-walled carbon nanotube/poly methyl methacrylate nanocomposites. *Journal of Applied Polymer Science*, *43738*, 1–10.

Naya, F., Molina-Aldaregu, J. M., Lopes, C. S., Gonzlez, C., and LLorca, J. (2016). Interface Characterization in Fiber-Reinforced Polymer–Matrix Composites. *Journal of Materials Science*, *16*, 13–21.

Nayak, P. S., and Singh, B. K. (2007). Instrumental characterization of clay by XRF, XRD and FTIR. *Bulletin of Materials Science*, *30*, 235–238.

Nazir, M. S., Haa, M., and Kassim, M. (2016). Characteristic Properties of Nanoclays and Characterization of Nanoparticulates and Nanocomposites, *Nanoclay Reinforced Polymer Composites*, 7, 35–56.

Njuguna, J., and Pielichowski, K. (2003). Polymer Nanocomposites for Aerospace Applications: Properties. *Advanced Engineering Materials*, *5*, 769–778.

Normand, G., Mija, A., Pagnotta, S., Peuvrel-Disdier, E., and Vergnes, B. (2017). Preparation of polypropylene nanocomposites by melt-mixing: Comparison between three organoclays. *Journal of Applied Polymer Science*, *20*, 1–8.

Novruzova, A., Ramazanov, M. A., and Chianese, A. (2017). Synthesis Structure and Optical Properties of PP + PbS / CdS Hybrid Nanocomposites, *60*, 61–66.

Numluk, P., and Chaisena, A. (2012). Sulfuric acid and ammonium sulfate leaching of alumina from Lampang clay. *E-Journal of Chemistry*, *9*, 1364–1372.

Nurdina, A. K., Mariatti, M., and and Samayamutthirian, P. (2009). Effect of Single-Mineral Filler and Hybrid-Mineral Filler Additives on the Properties of Polypropylene Composites. *Journal Vinyl Additive Technology*, *15*, 20–28.

O'Brien, D. J., Baechle, D. M., Wetzel, E. D. (2011). Design and performance of multifunctional structural composite capacitors. *Journal of Composite Materials.*, *45*, 2797–2809.

Ojijo, V., and Ray, S. S. (2014). Nano-biocomposites based on synthetic aliphatic polyesters and nanoclay. *Progress in Materials Science*, *62*, 1–57.

Olad, A. (2011). Polymer/Clay Nanocomposites. In *Advances in Diverse Industrial Applications of Nanocomposites* (p. 588). InTech.

Olaremu, A. G. (2015). Physico-Chemical Characterization of Akoko Mined Kaolin Clay. *Journal of Minerals and Materials Characterization and Engineering*, *3*, 353–361.

Palmqvist, A. E. C. (2003). Synthesis of ordered mesoporous materials using surfactant liquid crystals or micellar solutions. *Current Opinion in Colloid and Interface Science*, *8*, 103–108.

Panda, A. K., Mishra, B. G., Mishra, D. K., and Singh, R. K. (2010). Effect of sulphuric acid treatment on the physico-chemical characteristics of kaolin clay. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *363*, 98–104.

Pandey, J. K., Reddy, K. R., Mohanty, A. K., and Misra, M. (2014). *Handbook of Polymernanocomposites. Processing, Performance and Application*. *Book* (Vol.

A). Springer Berlin Heidelberg.

Parfitt, R., and Greenland, D. (1970). The adsorption of poly (ethylene glycols) on clay minerals. *Clay Minerals*, *8*, 305–315.

Parvinzadeh, M., and Eslami, S. (2011). Optical and electromagnetic characteristics of clay-iron oxide nanocomposites. *Research on Chemical Intermediates*, *37*, 771–784.

Parvinzadeh, M., Moradian, S., Rashidi, A., and Yazdanshenas, M. (2009). Surface characterization of polyethylene terephthalate / silica nanocomposites. *Applied Surface Science*, *256*, 2792–2802.

Passantino, J. M., Haywood, A. D., Goswami, J., and Davis, V. A. (2017). Effects of Polymer Additives and Dispersion State on the Mechanical Properties of Cellulose Nanocrystal Films. *Macromolecular Materials and Engineering*, *302*, 1–7.

Paul, D. R., and Robeson, L. M. (2008). Polymer nanotechnology: Nanocomposites. *Polymer*, *49*, 3187–3204.

Pavlidou, S., and Papaspyrides, C. D. (2008). A review on polymer-layered silicate nanocomposites. *Progress in Polymer Science (Oxford)*, *33*, 1119–1198.

Potts, P. J. (1987). X-ray fluorescence analysis: principles and practice of wavelenght dispersive spectrometry. *A Handbook of Silicate Rock Analysis*, 226–285.

Prakalathan, K., Mohanty, S., and Nayak, S. K. (2012). Polylactide/modified layered silicates nanocomposites: A critical analysis of morphological, mechanical and thermal properties. *Journal of Reinforced Plastics and Composites*, *31*, 1300–1310.

Prambauer, M., Paulik, C., and Burgstaller, C. (2016). Evaluation of the interfacial properties of polypropylene composite laminates, reinforced with paper sheets. *Composites Part A: Applied Science and Manufacturing*, *88*, 59–66.

Prater, K. (1990). The renaissance of the solid polymer fuel cell. *Journal of Power Sources*, *29*(1-2), 239-250.

Pui-Kwan Tse. (2013). *2013 Minerals Yearbook Malaysia [Advance Release]*. *U.S. Geological Survey*.

Pukánszky, B. (1990). Influence of interface interaction on the ultimate tensile properties of polymer composites. *Composites*, *21*, 255–262.

Pukánszky, B. (2005). Interfaces and interphases in multicomponent materials: Past,

present, future. *European Polymer Journal*, *41*, 645–662.

Qiu, X., Lei, X., Alshameri, A., Wang, H., and Yan, C. (2014). Comparison of the physicochemical properties and mineralogy of Chinese (Beihai) and Brazilian kaolin. *Ceramics International*, *40*, 5397–5405.

Rahim, N. A. A., Ariff, Z. M., Ariffin, A., and Jikan, S. S. (2011). Study on Effect of Filler Loading on the Flow and Swelling Behaviors of Polypropylene-Kaolin Composites Using Single-Screw Extruder. *Journal of Applied Polymer Science*, *119*, 73–83.

Rahim, N. A. A., Ariff, Z. M., Ariffin, A., Zakaria, Z., Osman, H., and Metselaar, H. C. (2014). Viscosity analysis of polypropylene-kaolin composites measured using single-screw extruder. *Journal of Vinyl and Additive Technology*, *20*, 275–283.

Rajesh, J. J., Soulestin, J., Lacrampe, M. F., and Krawczak, P. (2012). Effect of injection molding parameters on nanofillers dispersion in masterbatch based PP-clay nanocomposites. *Express Polymer Letters*, *6*, 237–248.

Ramírez, C., Albano, C., Karam, A., Domínguez, N., Sánchez, Y., and González, G. (2005). Mechanical, thermal, rheological and morphological behaviour of irradiated PP/HA composites. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, *236*, 531–535.

Red, C. (2008). Wind turbine blades: Big and getting bigger. *Composites Technology*, *6*, 42–47.

Reza Hashemi Farzad, Azman Hassan, M. Jawaid, M. A. M. P. (2013). Mechanical Properties of Alumina Trihydrate Filled Polypropylene / Ethylene Propylene Diene Monomer Composites for Cable Applications. *Sains Malaysiana*, *42*, 801–810.

Rimdusit, S., Smittakorn, W., Jittarom, S., and Tiptipakorn, S. (2011). Highly filled polypropylene rubber wood flour composites. *Engineering Journal*, *15*, 17–30.

Rong, J., Jing, Z., Li, H., and Sheng, M. (2001). A polyethylene nanocomposite prepared via in-situ polymerization. *Macromolecular Rapid Communications*, *22*, 329–334.

Ruiz-Hitzky, E., Aranda, P., Darder, M., and Fernandes, F. M. (2013). Fibrous clay mineral-polymer nanocomposites. *Developments in Clay Science*, *5*, 721–741.

Saat, A., Hamzah, Z., and Bakar, Z. A. (2008). XRF Determination of Major

Elemental Contents of Clay Samples from North-West Peninsular Malaysia. *Material Science Forum*, *888*, 1–8.

Sahari, J., Sapuan, S. M., Zainudin, E. S., and Maleque, M. A. (2013). Thermo-mechanical behaviors of thermoplastic starch derived from sugar palm tree (Arenga pinnata). *Carbohydrate Polymers*, *92*, 1711–1716.

Salwah, S., Jikan, B., Azam, N., Badarulzaman, Shehu, Y., and Adamu, A. D. (2017). Delamination of Kaolinite by Intercalation of Urea Using Milling. *Materials Science Forum*, *888*, 136–140.

Sanchez, C., Julián, B., Belleville, P., & Popall, M. (2005). Applications of hybrid organic–inorganic nanocomposites. *Journal of Materials Chemistry*, *15*(35-36), 3559-3592.

Santos, K. S., Liberman, S. A., Oviedo, M. A. S., and Mauler, R. S. (2009). Optimization of the mechanical properties of polypropylene-based nanocomposite via the addition of a combination of organoclays. *Composites: Part A*, *40*, 1199–1209.

Sapuan, S. M., and Bachtiar, D. (2012). Mechanical Properties of Sugar Palm Fibre Reinforced High Impact Polystyrene Composites. *Procedia Chemistry*, *4*, 101–106.

Saw, L. T., Uy Lan, D. N., Rahim, N. A. A., Mohd Kahar, A. W., and Viet, C. X. (2015). Processing degradation of polypropylene-ethylene copolymer-kaolin composites by a twin-screw extruder. *Polymer Degradation and Stability*, *111*, 32–37.

Sawyer, L., Grubb, D., and Meyers, G. F. (2008). *Polymer microscopy*. Springer Science and Business Media.

Sbeih, S., and Zihlif, M. (2009). Optical and electrical properties of kaolinite/polystyrene composite. *Journal of Physics D: Applied Physics*, *42*, 145405.

Selver, E., Potluri, P., Hogg, P., and Soutis, C. (2016). Impact damage tolerance of thermoset composites reinforced with hybrid commingled yarns. *Composites Part B: Engineering*, *91*, 522–538.

Sempeho, S. I., Kim, H. T., Mubofu, E., Pogrebnoi, A., Shao, G., and Hilonga, A. (2015). Dynamics of Kaolinite-Urea Nanocomposites via Coupled DMSO-Hydroxyaluminum Oligomeric Intermediates. *Indian Journal of Materials Science*, *2015*, 13–23.

Senatova, S. I., Senatov, F. S., Kuznetsov, D. V., Stepashkin, A. A., and Issi, J. P. (2017). Effect of UV-radiation on structure and properties of PP nanocomposites. *Journal of Alloys and Compounds*, *707*, 304–309.

Sengupta, P., Saikia, P. C., and Borthakur, P. C. (2008). SEM-EDX characterization of an iron-rich kaolinite clay. *Journal of Scientific and Industrial Research*, *67*, 812–818.

Shackelford, J.F. and Muralidhara, M. K. (2005). *Introduction to materials science for engineers* (7th ed.). Longman.

Shah, K. J., Shukla, A. D., Shah, D. O., and Imae, T. (2016). Effect of organic modifiers on dispersion of organoclay in polymer nanocomposites to improve mechanical properties. *Polymer (United Kingdom)*, *97*, 525–532.

Shahverdi-shahraki, K., and Chimique. (2014). *Development of PET/Kaolin Nanocomposites with Improved Mechanical properties*. École Poplytechnique de Monreal PhD. Thesis.

Sheikh, S. H., Yin, X., Ansarifar, A., and Yendall, K. (2017). The potential of kaolin as a reinforcing filler for rubber composites with new sulfur cure systems. *Journal of Reinforced Plastics and Composites*, *7(1) 157-171*.

Silva, R. C., Sarmento, M. V., Nogueira, F. A. R., Tonholo, J., Mortimer, R. J., Faez, R., and Ribeiro, A. S. (2014). Enhancing the electrochromic response of polyaniline films by the preparation of hybrid materials based on polyaniline, chitosan and organically modified clay. *RSC Advances*, *4*, 14948–14955.

Sinha Ray, S., and Okamoto, M. (2003). Polymer/layered silicate nanocomposites: A review from preparation to processing. *Progress in Polymer Science (Oxford)*, *28*, 1539–1641.

Smith, B. (1998). *Infrared Spectral Interpretation: a Systematic Approach.* CRC press.

Sobczak, L., Lang, R. W., and Haider, A. (2012). Polypropylene composites with natural fibers and wood - General mechanical property profiles. *Composites Science and Technology*, *72*, 550–557.

Sonal S. Karkhanis, Nicole M. Stark, R. C. S. and L. M. M. (2017). Blown film extrusion of poly(lactic acid) without melt strength enhancers. *Journal of Applied Polymer Science*, *134*.

Sousa, F. D. B. de, and Scuracchio, C. H. (2014). The use of atomic force microscopy as an important technique to analyze the dispersion of nanometric

fillers and morphology in nanocomposites and polymer blends based on elastomers. *Polímeros*, *24*, 661–672.

Spencer, M. W., Cui, L., Yoo, Y., and Paul, D. R. (2010). Morphology and properties of nanocomposites based on HDPE/HDPE-g-MA blends. *Polymer*, *51*, 1056–1070.

Srasra, E., and Trabelsi-Ayedi, M. (2000). Textural properties of acid activated glauconite. *Applied Clay Science*, *17*, 71–84.

Srivastava, S., Haridas, M., and Basu, J. K. (2008). Optical properties of polymer nanocomposites. *Bulletin of Materials Science*, *31*, 213–217.

Stadler, F. J. (2011). Dynamic-mechanical behavior of polyethylenes and ethene/α-olefin-copolymers: Part II. α- and β-relaxation. *Korean Journal of Chemistry Engineering*, *28*, 954–963.

Su, S., and Wilkie, C. A. (2004). The thermal degradation of nanocomposites that contain an oligomeric ammonium cation on the clay. *Polymer Degradation and Stability*, *83*, 347–362.

Sudha, J. D., Sivakala, S., Prasanth, R., Reena, V. L., and Radhakrishnan Nair, P. (2009). Development of electromagnetic shielding materials from the conductive blends of polyaniline and polyaniline-clay nanocomposite-EVA: Preparation and properties. *Composites Science and Technology*, *69*, 358–364.

Šupová, M., Martynková, G. S., and Barabaszová, K. (2011). Effect of Nanofillers Dispersion in Polymer Matrices: A Review. *Science of Advanced Materials*, *3*, 1–25.

Suraj, G., Iyer, C. S. P., and Lalithambika, M. (1998). Adsorption of cadmium and copper by modified kaolinites. *Applied Clay Science*, *13*, 293–306.

TA, I. (2011). Thermal Analysis. *TA Instruments*, 1–11.

Tabi, T., Bakonyi, P., Hajba, S., Herrera-Franco, P., Czigany, T., and Kovacs, J. (2016). Creep behaviour of injection-moulded basalt fibre reinforced poly(lactic acid) composites. *Journal of Reinforced Plastics and Composites*, *35*, 1600–1610.

Tang, W., Song, L., Zhang, S., Li, H., Sun, J., and Gu, X. (2017). Preparation of thiourea-intercalated kaolinite and its influence on thermostability and flammability of polypropylene composite. *Journal of Materials Science*, *52*, 208–217.

Telysheva, G., Dizhbite, T., Paegle, E., Shapatin, A., and Demidov, I. (2001).

Synthesis and air separation of soluble terpolymers from aniline, toluidine, and xylidine. *Journal of Applied Polymer Science*, *82*, 790–798.

Teng, L., Ngoc, D., Lan, U., Azura, N., Rahim, A., Wahab, A., and Kahar, M. (2015). Processing degradation of polypropylene-ethylene copolymer-kaolin composites by a twin-screw extruder. *Polymer Degradation and Stability*, *111*, 32–37.

Thiraphattaraphun, L. (2013). *Structure / Property Relationships in Polypropylene Nanocomposites*. University of Manchester. PhD Thesis.

Thomsen, M. R. (2013). *Electronic and Optical Properties of Graphene and Graphene Antidot Structures*. *(Doctoral dissertation)*, University of Aalborg.

Throne, J. (2005). *Thermoplastic Foam Estrusion*. *New York*. London New York Washington, D.C: CRC press.

Thye, C., Seman, C., Amran, M., and Salleh, M. (2011). The study of aluminum loss and consequent phase transformation in heat-treated acid-leached kaolin. *Materials Characterization*, *62*, 373–377.

Trabelsi, W., and Tlili, A. (2017). Phosphoric acid purification through different raw and activated clay materials (Southern Tunisia). *Journal of African Earth Sciences*, *129*, 647–658.

Tripathi, D. (2014). *Practical Guide to polproylene*. iSmithers Rapra Publishing.

Truong, J. (2017). *Chemistry II*. McGraw-Hill Book Company, Inc. United States of America.

Tsuji, M., Nishizawa, Y., Matsumoto, K., Miyamae, N., Tsuji, T., and Zhang, X. (2007). Rapid synthesis of silver nanostructures by using microwave-polyol method with the assistance of Pt seeds and polyvinylpyrrolidone. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *293*, 185–194.

Turcsan, T., and Meszaros, L. (2017). Mechanical performance of hybrid thermoset composites: Effects of matrix and reinforcement hybridization. *Composites Science and Technology*, *141*, 32–39.

Turhan, Y., Dog, M., and Alkan, M. (2010). Poly (vinyl chloride)/Kaolinite Nanocomposites : Characterization and Thermal and Optical Properties. *Industrial and Engineering Chemistry Research*, *49*, 1503–1513.

Unal, H., Findik, F., and Mimaroglu, A. (2003). Mechanical behavior of nylon composites containing talc and kaolin. *Journal of Applied Polymer Science*, *88*, 1694–1697.

Urbanczyk, L., Ngoundjo, F., Alexandre, M., Jérôme, C., Detrembleur, C., and Calberg, C. (2009). Synthesis of polylactide/clay nanocomposites by in situ intercalative polymerization in supercritical carbon dioxide. *European Polymer Journal*, *45*, 643–648.

Urbaniak-domagala, W. (2012). The Use of the Spectrometric Technique FTIR-ATR to Examine the Polymers Surface. *Advanced Apects of Spectroscopy*, 86–104.

Valá, M., Barabaszová, K., Hundáková, M., Ritz, M., and Plevová, E. (2011). Effects of brief milling and acid treatment on two ordered and disordered kaolinite structures. *Applied Clay Science*, *54*, 70–76.

Valášková, M., Barabaszová, K., Hundáková, M., Ritz, M., and Plevová, E. (2011). Effects of brief milling and acid treatment on two ordered and disordered kaolinite structures. *Applied Clay Science*, *54*, 70–76.

Valášková, M., Rieder, M., V.Matějka, Čapková, P., and Slíva, A. (2007). Exfoliation/delamination of kaolinite by low-temperature washing of kaolinite-urea intercalates. *Applied Clay Science*, *35*, 108–118.

Vandecasteele, F. V. (1992). Determination of the surface area by the BET method. *Talanta*, *39*, 131–142.

Varnagiris, S., Girdzevicius, D., Urbonavicius, M., and Darius Milcius. (2017). Incorporation of SiO_2 and TiO_2 additives into expanded polystyrene foam using physical vapour deposition technique. *Energy Procedia*, *128*, 525–532.

Verbeek, C. J. R. (2003). The influence of interfacial adhesion, particle size and size distribution on the predicted mechanical properties of particulate thermoplastic composites. *Materials Letters*, *57*, 1919–1924.

Waché, R., Klopffer, M., and Gonzalez, S. (2015). Characterization of Polymer Layered Silicate Nanocomposites by Rheology and Permeability Methods: Impact of the Interface Quality. *Oil and Gas Science and Technology – Revue d'IFP Energies Nouvelles*, *70*, 267–277.

Wang, B., Ma, H., Wu, D., Zhu, L. and Jin, Z. (2017). Toughening polypropylene by tiny amounts of fillers. *Pigment and Resin Technology*, *46*, 2–58.

Wang, E., Shi, F., and Manlapig, E. (2012). Mineral liberation by high voltage pulses and conventional comminution with same specific energy levels. *Minerals Engineering*, *27–28*, 28–36.

Wang, L., He, X., and Wilkie, C. A. (2010). The utility of nanocomposites in fire retardancy. *Materials*, *3*, 4580–4606.

Wang, L., Wu, D., Yuan, P., Chen, Z., and Chen, Z. (2002). ^{1}H MAS NMR spectra of kaolinite/formamide intercalation compound. *Chinese Science Bulletin*, *47*, 1–4.

Wang, R. M., Zheng, S. R., and Zheng, Y. P. (2011). *Introduction to polymer matrix composites*. *Polymer matrix composites and technology*. Science Press.

Wang, R., Zheng, S., and Zheng, Y. G. (2011). *Polymer Matrix Composites and Technology*.

Wang, X., Jiang, M., Zhou, Z., Gou, J., and Hui, D. (2017). 3D printing of polymer matrix composites: A review and prospective. *Composites Part B: Engineering*, *110*, 442–458.

Watson,. E., O'neill, M. J., Justin, J., and Brenner, N. (1964). A Differential Scanning Calorimeter for Quantitative Differential Thermal Analysis. *Analytical Chemistry*, *36*, 1233–1238.

White, S. R., and Hahn, H. T. (1967). Process modeling of composite materials: residual stress development during cure. Part II. Experimental validation. *Journal of Composite Materials*, *26*, 2423–2453.

Wilhelm, H. M., Sierakowski, M. R., Souza, G. P., and Wypych, F. (2003). Starch films reinforced with mineral clay. *Carbohydrate Polymers*, *52*, 101–110.

Worasith, N., Goodman, B. A., Neampan, J., and Jeyachoke, N. (2011). Characterization of modified kaolin from the Ranong deposit Thailand by XRD, XRF, SEM, FTIR and EPR techniques. *Clay Mineral*, *46*, 539–559.

Wypych, F. (2000). Layered polymer-kaolinite nanocomposites. *Journal of Materials Science*, *35*, 3113–3119.

Xanthos, M. (2016). Polymers and Fillers. *Materials*, *3*, 1–15.

Xiumei, Q. I. U., Yadong, L. I. U., Aref, A., Xiaoyan, Z. H. U., and Chunjie, Y. A. N. (2017). Viscosity of Kaolin Slurries : Effects of Dispersant and Urea-Intercalation. *Journal of Wuhan University of Technology-Material Science Edition*, *32*, 51–57.

Xu, Y., Brittain, W. J., Xue, C., and Eby, R. K. (2004). Effect of clay type on morphology and thermal stability of PMMA-clay nanocomposites prepared by heterocoagulation method. *Polymer*, *45*, 3735–3746.

Yan, L., Zhang, C., and Xu, Z. (2008). Highly effective delamination of kaolinite and emergence of a novel nanoclub-like crystal. *Journal Wuhan University of Technology, Materials Science Edition*, *23*, 566–570.

Yang, N., Zhang, Z. C., Ma, N., Liu, H. L., Zhan, X. Q., Li, B., ... & Chiang, T. C. (2017). Effect of surface modified kaolin on properties of polypropylene grafted maleic anhydride. *Results in physics*, *7*, 969-974.

Yi, D., Yang, H., Zhao, M., Huang, L., Camino, G., Frache, A., and Yang, R. (2017). A novel, low surface charge density, anionically modified montmorillonite for polymer nanocomposites. *RSC Advances.*, *7*, 5980–5988.

Yildirim, I. (2001). *Surface free energy characterization of powders*. Faculty of the Virginia Polytechnic Institute and State University.

Yiping, H., Guangmei, C., Zhen, Y., Hongwu, L., and Yong, W. (2005). Non-isothermal crystallization behavior of polypropylene with nucleating agents and nano-calcium carbonate. *European Polymer Journal*, *41*, 2753–2760.

Yonezawa, T., Yamanoi, Y., and Nishihara, H. (2008). Cross-sectional STEM observation of nanoparticle-attached silicon wafer: specimen prepared by focused ion-beam. *Journal of Nanoscience Nanotechnology*, *8*, 1518–1522.

Zaharia, A., Perrin, F. X., Teodorescu, M., Radu, A. L., Iordache, T. V., Florea, A. M., and Sarbu, A. (2015). *Phys. Chem.* (Vol. 17).

Zare, Y. (2017). An approach to study the roles of percolation threshold and interphase in tensile modulus of polymer/clay nanocomposites. *Journal of Colloid and Interface Science*, *486*, 249–254.

Zdiri, K., Elamri, A., and Hamdaoui, M. (2017). Advances in Thermal and Mechanical Behaviors of PP/Clay Nanocomposites. *Polymer-Plastics Technology and Engineering*, *56*, 824–840.

Zeng, Q. H., Yu, A B., Lu, G. Q., and Paul, D. R. (2005). Clay-based polymer nanocomposites: research and commercial development. *Journal of Nanoscience and Nanotechnology*, *5*, 1574–1592.

Zhang, S., Liu, Q., Cheng, H., Li, X., Zeng, F., and Frost, R. L. (2014). Intercalation of dodecylamine into kaolinite and its layering structure investigated by molecular dynamics simulation. *Journal of Colloid and Interface Science*, *430*, 345–350.

Zhang, Y., Song, H., Liu, Q., Zhang, S., and Zhang, Y. (2017). Dynamic Mechanical Property of Kaolinite/Styrene-Butadiene Rubber Composites. *Mechanics, Materials Science and Engineering*, *3*, 127–151.

Zhao, X., Bai, L., Bao, R., Liu, Z., Yang, M., and Yang, W. (2017). Excellent mechanical performance and enhanced dielectric properties of OBC/SiO_2

elastomeric nanocomposites: effect of dispersion of the SiO_2 nanoparticles. *RSC Advances.*, *7*, 46297–46305.

Zulkifli M. A, Azlan A, Suzi S.J, and Nor Azura A. (2012). Rheological Behaviour of Polypropylene Through Extrusion and Capillary Rheometry. *Polypropylene*, 7(6) 29–48.

Zýková, J., Kalendová, A., Mat, V., Jka, Ě., and Valášková, M. (2010). Kaolinite-Urea Intercalates for PVC Nanocomposites. *Nanocomposites*, *10*, 10–14.

Zykova, J., Kalendova, A., Matejka, V., and Zadrapa, P. (2013). Influence of kaolinite modification on the PVC composites properties. *Advances in Sensor, Signals and Materials*, *17*, 30–34.